

Chapter 15

Stratigraphic Framework of the Cretaceous Mowry Shale, Frontier Formation and Adjacent Units, Southwestern Wyoming Province, Wyoming, Colorado, and Utah

By Mark A. Kirschbaum and Laura N.R. Roberts

Chapter 15 of

Petroleum Systems and Geologic Assessment of Oil and Gas in the Southwestern Wyoming Province, Wyoming, Colorado, and Utah

By USGS Southwestern Wyoming Province Assessment Team

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Abstract

A stratigraphic framework of source and reservoir rocks in the Mowry Composite Total Petroleum System was developed to support the characterization and assessment of oil and gas resources in the total petroleum system in the Southwestern Wyoming Province of Wyoming, Colorado, and Utah. The Mowry Composite Total Petroleum System includes the Lower Cretaceous Dakota Sandstone, Cloverly Formation, Thermopolis Shale, and Shell Creek Shale, and the Upper Cretaceous Mowry Shale and Frontier Formation. Four regional stratigraphic cross sections were constructed to show the subsurface distribution and correlation of these formations in various parts of the province, as well as the different facies represented. Detailed lithologic descriptions were obtained from cored intervals in a few wells, and surface sections at three widely separated localities provided key information on formation ages and stratigraphic relations. Isopach and structure contour maps of the Frontier Formation were also prepared to show the three-dimensional distribution of the units within the province.

Introduction

The purpose of this study was to illustrate the stratigraphic framework of source and reservoir rocks of the Mowry Total Petroleum System in support of the characterization and assessment of undiscovered oil and gas resources in the Southwestern Wyoming Province (Kirschbaum and Roberts, Chapter 5, this CD-ROM). The study consists of four regional stratigraphic cross sections (fig. 1; pls. 1–4), 10 core descriptions of the Frontier Formation, an isopach map of members of the Frontier Formation, a structure contour map on top of the Frontier, and a database of records for depths to the base and top of the Mowry Shale and to the tops of the members of the Frontier Formation as interpreted from 156 drill holes (table 1).

The main focus of the study was the Upper Cretaceous Mowry Shale and Frontier Formation, exclusive of the first Frontier sandstone. The cores were chosen to investigate as many different stratigraphic intervals as possible in the Fron-

tier Formation, interpret basic depositional environments, and calibrate rock types with geophysical logs. Core descriptions by Stands (1999) and interpretations by Hamlin (1996) also were used to help map units and to determine their depositional environments. Reconnaissance observation of three outcrop sections were made at Muddy Gap and Blazon Gap in Wyoming and south of the town of Manila near Flaming Gorge in Utah (fig. 1). At Muddy Gap, interpretations of sedimentary structures were added to a section measured by Mieras (1993) and incorporated into cross section D–D' (pl. 4).

Stratigraphic units were defined and mapped using geophysical logs in the subsurface, published subsurface cross sections, and observed surface sections. Key stratigraphic studies include Merewether (1983), Hamlin (1996), and Stands (1999) for the Frontier Formation and Ryer and others (1987) for the Lower Cretaceous Dakota Sandstone. Comprehensive studies by private companies on the Dakota and the Frontier have not been publicly released; however, some correlations and stratigraphic terminology from those reports have been incorporated into some publications (for example, Miller and others, 1992) and are noted on the cross sections (pls. 1–4). In addition to the Mowry Shale and Frontier Formation, other units were correlated in less detail, including the Dakota Sandstone, Cloverly Formation, Thermopolis Shale including the Muddy Sandstone Member, and Shell Creek Shale, all of Early Cretaceous age, and the first Frontier sandstone, and the lower part of the marine shale facies equivalent to the Hilliard, Baxter, Steele, and Cody Shales, which are of Late Cretaceous age (see fig. 2).

Acknowledgments

Discussions with Jeff May, Ira Pasternack, Donna Anderson, Peter McCabe, and Al Merewether improved our understanding of the stratigraphy. Thorough reviews by Tom Finn, Ron Johnson, and Dick Keefer greatly improved the report. We are also grateful to Chris French and Steve Cazenave for their diligence in tracing the geophysical logs used in the cross sections.

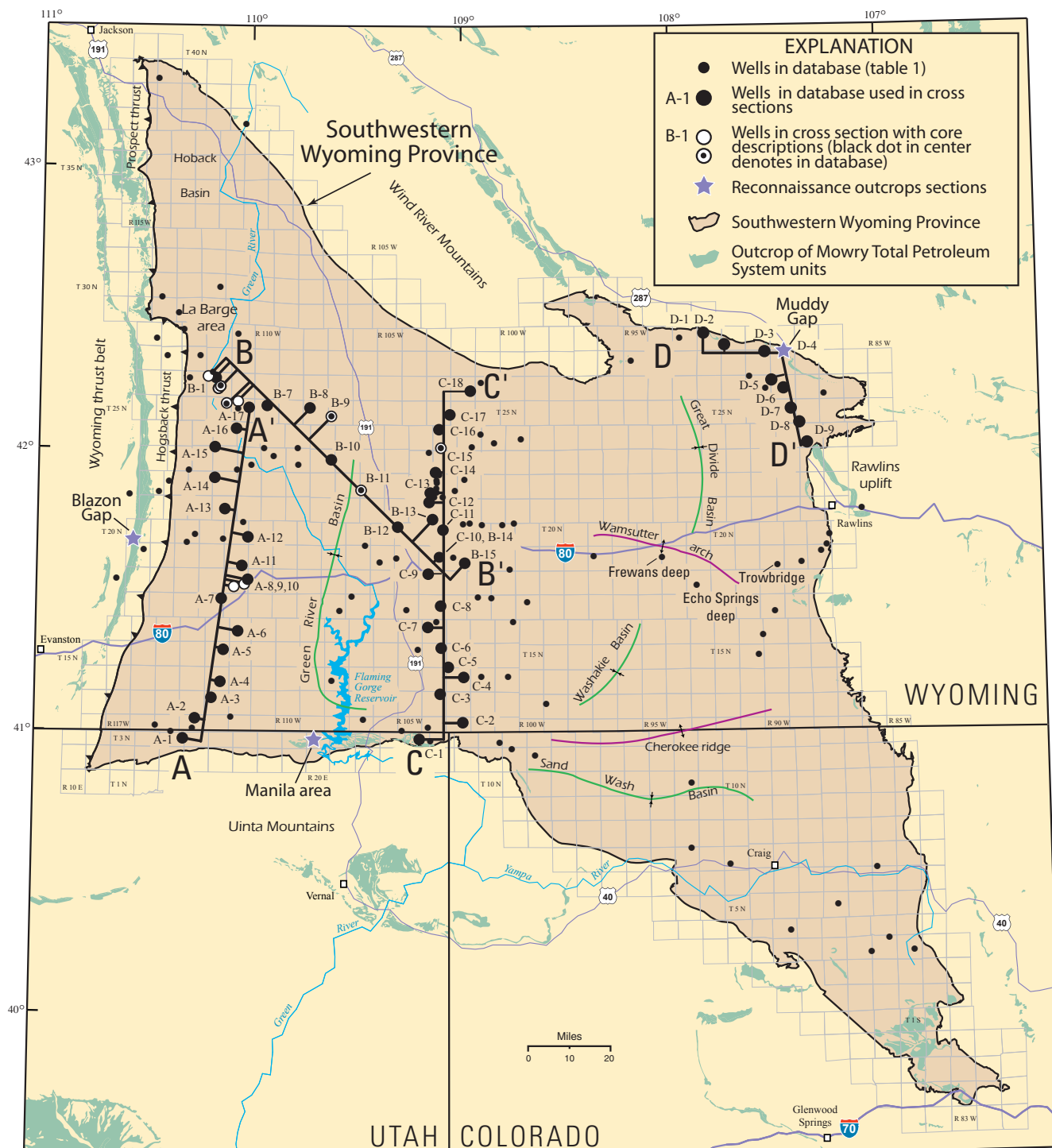


Figure 1. Index map showing lines of cross sections, data points used in database, locations of reconnaissance outcrop sections, and major structural elements within the Southwestern Wyoming Province. The wells used in cross section A–A' (pl. 1) generally define the location of the Moxa arch, and cross section C–C' (pl. 3) generally shows the location of the Rock Springs uplift.

Table 1. Well data showing depths to selected stratigraphic horizons within the Thermopolis Shale, Mowry Shale, and Frontier Formation in the Southwestern Wyoming Province, and thicknesses (column FT) of the Frontier Formation.

[ELEV, elevation of Kelly bushing (KB), ground level (GR), or drill floor (DF) in feet above mean sea level. Values in all but the last column are depths, in feet; last column is thickness, in feet. Abbreviations used: TM, top of the Thermopolis Shale or in some cases the Dakota Sandstone; SH, top of the Shell Creek Shale; ML, top of the lower Mowry Shale (blue interval on pls. 1–4); MU, top of the Mowry Shale (purple interval on pls. 1–4); BF, top of the Belle Fourche Member over most of the area but includes the lower part of the Chalk Creek in the thrust belt (base of Stands, 1999, Chalk Creek sequence boundary); CC, top of the Chalk Creek Member of the Frontier; AH, top of the Allen Hollow Shale Member of the Frontier; OE, combined tops of the Oyster Ridge Sandstone and Emigrant Gap Members, and includes any shoreface sandstones associated with the Dry Hollow Member of the Frontier in the Washakie Basin; DW, combined tops of the Dry Hollow and Wall Creek Members of the Frontier Formation; FT, Frontier thickness from top of DW to top of MU. Blank cells indicate no data. Locations of data points are shown in figure 5.]

Map no.	API number	Well name	Section	Township	Range	State	ELEV	TM	SH	ML	MU	BF	CC	AH	OE	DW	FT
1	49041207120000	CPC Whitney Creek 34-15	15	18N	117W	WY	6,646	KB		6,610	6,455	5,725	4,750	4,350	4,250	3,895	2,560
2	49023206100000	Gary Huckabay 34-15	34	22N	116W	WY	7,056	KB	6,808	6,440	6,275	5,530	4,500	4,258	4,010	3,194	3,081
3	49023203550000	Champlin 406 Amoco-A	11	19N	116W	WY	7,000	GR	15,635	15,532	15,175	14,960	14,860	14,815	14,750	14,640	440
4	49039200180000	Williams Granite Ck 1-30	30	39N	113W	WY	6,753	KB	15,570	15,353	1,587	14,930	14,758	14,600	14,600	14,505	760
5	49035205070000	Dome Fogarty 1-26	26	28N	115W	WY	9,736	GR					8,550	8,550	8,428	8,237	
6	49041208140000	Texaco TPI 1	13	12N	116W	WY	9,276	KB	15,605	15,570	15,325	15,225	15,110	15,110	15,110	15,100	175
7	49023204670000	Natural Gas Federal 31-35A	35	22N	115W	WY	7,343	KB			14,190	14,150	13,910	13,910	13,770	13,650	540
8	49035206730000	Amer. Quasar Riley Ridge 33-24	33	30N	114W	WY	8,297	KB	9,200	8,858	8,528	8,430	8,340	8,030	8,030	7,980	540
9	49035205540000	Exxon Graphite 1	16	27N	114W	WY	9,213	GR	10,382	10,180	9,930	9,760	9,465	9,300	9,300	9,255	780
10	49023201250000	American Quasar Sun Fed 1	17	22N	114W	WY	7,278	GR	14,070	13,875	13,495	13,365	13,330	13,120	13,120	12,980	470
11	49041207720000	Anadarko Graham A-2	22	12N	115W	WY	9,492	KB	15,800	15,758	15,450	15,380	15,380	15,380	15,360	15,300	80
12	49035206180000	Mobil TR2 57-19GT	19	29N	113W	WY	7,815	KB	8,625	8,462	8,205	8,015	7,770	7,680	7,680	7,590	545
13	49035057950000	Mobil Tip Top	18	28N	113W	WY	7,946	KB	8,218	8,078	7,840	7,680	7,560	7,290	7,290	7,250	560
14	43043203030000	Phillips Fork A 9	24	3N	14E	UT	8,892	KB	15,190	15,175	14,940	14,940	14,940	14,940	14,898	14,840	100
15	49023204140000	Champlin 262 Amoco B	33	20N	114W	WY	6,608	KB	12,995	12,900	12,615	12,405	12,405	12,405	12,305	12,240	165
16	49023206930001	Enron 13-8A	8	26N	113W	WY	7,206	KB		7,915	7,650	7,479	7,330	7,225	7,225	7,110	474
17	49023206240000	Exxon Graham Reservoir 1	36	23N	114W	WY	6,853	KB	12,610	12,412	12,065	11,940	11,885	11,710	11,710	11,620	410
18	49041207240001	Sun (Oryx) Luckey Fed 2	22	12N	114W	WY	8,420	KB	14,690	14,662	14,408	14,408	14,408	14,408	14,390	14,325	83
19	49023204150000	Champlin 262 Amoco C1	23	20N	114W	WY	6,666	GR	12,753	12,658	12,355	12,155	12,155	12,155	12,120	11,970	185
20	49041207600000	Diamond Taylor Ranch 33-3	3	12N	114W	WY	8,140	KB	14,269	14,239	13,998	13,998	13,998	13,998	13,950	13,904	94
21	49035054500000	California Birch Creek 1	14	27N	113W	WY	7,030	GR	7,730	7,540	7,290	7,150	7,010	6,830	6,830	6,690	460
22	49035211860000	Enron East Labarge 55-32	32	27N	112W	WY	6,588	KB					7,060	6,965	6,965	6,920	6,860
23	49041206150000	Forest Henry 11	8	13N	113W	WY	7,286	GR	13,440	13,418	13,172	13,172	13,172	13,172	13,120	13,092	80
24	49023207260000	CNG Graham 2-6	6	23N	112W	WY	6,724	KB	11,460	11,310	10,982	10,862	10,845	10,745	10,617	10,556	306
25	49023204240000	Amoco Shute Creek 8	7	22N	112W	WY	6,543	KB	11,590	11,458	11,147	11,023	10,980	10,877	10,877	10,705	318
26	49023206330000	Enron West Stead 12-9	9	26N	112W	WY	6,949	KB	8,358	8,183	7,926	7,760	7,676	7,446	7,446	7,420	466
27	49035205280000	Woods Guio 23-1	23	30N	112W	WY	6,936	KB	14,046	13,892	13,675	13,541	13,450	13,190	13,190	13,014	527
28	49023204680000	Natural Gas Fontenelle 22-22B	22	26N	112W	WY	9,045	KB	8,500	8,328	8,075	7,918	7,772	7,635	7,635	7,457	461
29	49041201720000	Wexpro Butcher Knife 6	22	14N	113W	WY	7,269	KB	13,243	13,211	12,990	12,990	12,990	12,990	12,967	12,920	70
30	49041207190000	Celsius Thompson 12-1	12	17N	113W	WY	6,689	KB	12,599	12,535	12,255	12,200	12,200	12,200	12,164	12,069	131

Table 1. Well data showing depths to selected stratigraphic horizons within the Thermopolis Shale, Mowry Shale, and Frontier Formation in the Southwestern Wyoming Province, and thicknesses (column FT) of the Frontier Formation.—Continued

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31	49023200440000	Amoco Wilson Ranch 1	25	20N	113W	WY	6,680	KB	12,170	12,090	11,650	11,568	11,530	11,530	11,530	11,500	11,440	128
Map no.	API number	Well name	Section	Township	Range	State	ELEV		TM	SH	ML	MU	BF	CC	AH	OE	DW	FT
32	49023207320000	Amoco Whiskey Buttes 48	21	21N	112W	WY	6,671	KB	11,870	11,736	11,393	11,273	11,273	11,239	11,239	11,170	11,133	140
33	49041201710000	Champlin CPC 24-11	11	15N	113W	WY	6,910	KB	13,000	12,960	12,720	12,720	12,720	12,720	12,720	12,670	12,628	92
34	49023202760000	Pacific Fed 43-11	11	25N	112W	WY	7,020	GR							8,712	8,630	8,535	
35	49041207820000	Sun Wadsworth 1	6	12N	112W	WY	7,319	KB	14,570	14,520	14,385	14,320	14,320	14,320	14,320	14,303	14,235	85
36	49023202780000	NW Exploration Fontenelle	12	24N	112W	WY	6,685	KB	10,584	10,442	10,119	9,995	9,955	9,852	9,852	9,777	9,681	314
37	49035205780000	Woods USA & Reardon 17-1	17	28N	111W	WY	6,777	KB	12,100	11,985	11,740	11,590	11,530	11,335	11,335	11,280	11,180	410
38	49023208050000	Amoco Cow Hollow 16	36	23N	112W	WY	6,564	KB	11,415	11,265	10,975	10,900	10,810	10,725	10,725	10,660	10,570	330
39	49023206680000	Terra 3-17	17	25N	111W	WY	6,989	KB					9,265	9,175	9,175	9,090	8,990	
40	49037222680000	Wexpro Unit 31	21	16N	112W	WY	7,091	KB	12,685	12,641	12,392	12,392	12,392	12,392	12,392	12,350	12,280	112
41	49035209170000	HPC Inc New Forks 32-27	27	37N	110W	WY	7,641	KB	4,300	4,120	3,823	3,687	3,490	3,440	3,350	3,285	2,590	1,097
42	49037219330000	Amoco 149 F1	35	19N	112W	WY	6,298	KB	11,895	11,818	11,523	11,440	11,440	11,440	11,440	11,410	11,323	117
43	49037217810000	C&K Seven Mile #13	2	20N	112W	WY	6,442	KB	12,000	11,930	11,480	11,418	11,418	11,418	11,418	11,340	11,270	148
44	49037213310000	Energetics Fed 23-14	14	25N	111W	WY	6,885	KB	10,140	10,017	9,693	9,578	9,529	9,438	9,438	9,362	9,268	310
45	49037227530000	Amoco 326 D2	25	20N	112W	WY	6,433	KB	12,300	12,210	11,900	11,815	11,815	11,815	11,815	11,782	11,660	155
46	49037227480000	Amoco 206 C2	13	18N	112W	WY	6,389	KB	12,323	12,260	11,978	11,900	11,900	11,900	11,900	11,860	11,756	144
47	49037231530000	Presido Haven 22-27	27	23N	111W	WY	6,458	KB	11,280	11,147	10,865	10,780	10,690	10,670	10,670	10,590	10,525	255
48	49037215150000	Davis East Storm Shelter 1	6	23N	110W	WY	6,406	GR	11,148	11,010	10,765	10,657	10,510	10,510	10,510	10,450	10,370	287
49	49037218050000	Energetics 44-9	9	25N	110W	WY	6,688	KB	10,874	10,716	10,445	10,345	10,230	10,180	10,180	10,110	9,952	393
50	49037231790000	Washington Horseshoe 31-16	16	23N	110W	WY	6,396	KB	11,480	11,365	11,120	11,020	10,965	10,900	10,900	10,835	10,770	250
51	49037226880000	Washington Energy 32-4	4	23N	109W	WY	6,437	KB	14,965	14,818	14,564	14,478	14,395	14,395	14,395	14,308	14,220	258
52	49037208070000	Davis Buckhorn 1	28	23N	109W	WY	6,394	KB			14,770	14,685	14,620	14,570	14,570	14,530	14,455	230
53	49037219270000	Amer. Hunter Faraway	17	25N	108W	WY	6,900	GR	15,915	15,811	15,549	15,453	15,330	15,270	15,270	15,208	15,040	413
54	49037219540000	American Enterprise 1A	30	25N	107W	WY	6,737	GR	16,648	16,552	16,293	16,220	16,070	16,070	16,070	15,998	15,910	310
55	49037206500000	Kansas Sandy Bend	14	23N	108W	WY	6,524	KB	15,686	15,603	15,346	15,275	15,155	15,155	15,155	15,096	15,019	256
56	49037205590100	Brown 1 Current Ck	20	14N	108W	WY	6,254	KB	17,198	17,170	17,040	16,980	16,955	16,955	16,955	16,889	16,806	174
57	49037210660000	Huskey Massacre Hills 3-26	26	17N	108W	WY	6,616	KB	16,190	16,152	15,980	15,920	15,825	15,825	15,825	15,808	15,730	190
58	49037210920000	Huskey Massacre Hills 11-5	5	17N	107W	WY	6,801	KB	16,150	16,103	15,954	15,890	15,789	15,789	15,789	15,770	15,660	230
59	49037220590000	Energy Blue Rim	30	22N	106W	WY	6,737	KB	16,668	16,600	16,348	16,290	16,135	16,135	16,135	16,083	16,040	250
60	49037201570000	Forest Oil Gov 1-3	3	12N	107W	WY	7,026	KB	15,830	15,800	15,680	15,580	15,580	15,580	15,580	15,530	15,450	130
61	49037219580000	Davis 1 Dagger Unit	2	19N	107W	WY	6,724	KB	16,831	16,776	16,575	16,510	16,374	16,374	16,374	16,332	16,240	270
62	49037211280000	Davis Poitevent Fed 1	28	19N	106W	WY	7,368	KB	15,195	15,158	14,980	14,910	14,790	14,790	14,790	14,740	14,680	230
63	49037202850000	Union Oil White Mtn 1-C-19	19	19N	105W	WY	7,570	KB	14,960	14,920	14,750	14,680	14,510	14,510	14,510	14,460	14,415	265

Table 1. Well data showing depths to selected stratigraphic horizons within the Thermopolis Shale, Mowry Shale, and Frontier Formation in the Southwestern Wyoming Province, and thicknesses (column FT) of the Frontier Formation.—Continued

[ELEV, elevation of Kelly bushing (KB), ground level (GR), or drill floor (DF) in feet above mean sea level. Values in all but the last column are depths, in feet; last column is thickness, in feet. Abbreviations used: TM, top of the Thermopolis Shale or in some cases the Dakota Sandstone; SH, top of the Shell Creek Shale; ML, top of the lower Mowry Shale (blue interval on pls. 1–4); MU, top of the Mowry Shale (purple interval on pls. 1–4); BF, top of the Belle Fourche Member over most of the area but includes the lower part of the Chalk Creek in the thrust belt (base of Stands, 1999, Chalk Creek sequence boundary); CC, top of the Chalk Creek Member of the Frontier; AH, top of the Allen Hollow Shale Member of the Frontier; OE, combined tops of the Oyster Ridge Sandstone and Emigrant Gap Members, and includes any shoreface sandstones associated with the Dry Hollow Member of the Frontier in the Washakie Basin; DW, combined tops of the Dry Hollow and Wall Creek Members of the Frontier Formation; FT, Frontier thickness from top of DW to top of MU. Blank cells indicate no data. Locations of data points are shown in figure 5.]

Map no.	API number	Well name	Section	Township	Range	State	ELEV	TM	SH	ML	MU	BF	CC	AH	OE	DW	FT
64	49037209650000	H P C Dines 1	7	20N	105W	WY	6,679 KB	13,490	13,431	13,224	13,155	13,017	13,017	13,017	12,960	12,896	259
65	49037064180000	Mountain Fuel Rich. Mtn 1	19	12N	105W	WY	6,986 KB		8,190	7,990	7,990	7,990	7,990	7,990	7,900	7,840	150
66	49037207510000	Davis 1 Little Miller Canyon	21	17N	105W	WY	6,523 GR	7,030	6,978	6,820	6,750	6,650	6,650	6,650	6,615	6,538	212
67	49037211570000	Silver Dollar #1	11	15N	105W	WY	7,539 KB	8,202	8,167	8,035	7,975	7,920	7,920	7,920	7,870	7,790	185
68	43009300280000	MFS Clay Basin 37-S	27	3N	24E	UT	6,464 KB	5,763	5,738	5,630	5,595	5,583	5,583	5,583	5,517	5,392	203
69	49037224590000	Terra Kappes Canyon 10-17	17	16N	104W	WY	7,632 KB	5,568	5,532	5,398	5,339	5,241	5,241	5,241	5,226	5,131	208
70	49037207540000	Marathon Tepee Mtn II	17	12N	104W	WY	8,190 KB		10,955	10,760	10,760	10,760	10,760	10,760	10,690	10,595	165
71	49037220480000	Columbine Grace Fed. 4-1	4	18N	104W	WY	6,661 KB	4,896	4,852	4,695	4,630	4,455	4,455	4,455	4,440	4,344	286
72	49037235000001	Yates Depot 4	11	21N	104W	WY	7,114 KB	6,430	6,379	6,193	6,125	5,930	5,930	5,930	5,878	5,788	337
73	49037214390000	Texas Winston Fed 1	2	23N	104W	WY	6,452 KB	9,272	9,205	9,005	8,934	8,735	8,720	8,720	8,667	8,572	362
74	49037209230000	Luff Amoco 1-25	25	22N	104W	WY	7,096 KB	7,435	7,397	7,200	7,134	6,904	6,904	6,904	6,874	6,758	376
75	43009300370000	Artus Sherwin Fed 12-30	30	3N	25E	UT	6,990 KB	7,212	7,200	7,010	7,010	7,010	7,010	7,010	6,940	6,815	195
76	49037238360000	Yates Roundhouse 1	36	21N	104W	WY	6,706 KB	4,895	4,844	4,670	4,597	4,406	4,406	4,406	4,365	4,291	306
77	49037214990000	Christmann 1-31	31	22N	103W	WY	7,242 KB					6,090	6,070	6,070	6,030	5,935	
78	49037226500000	Pacific Entpr. Oil	31	23N	103W	WY	6,967 KB	8,428	8,366	8,177	8,106	7,892	7,874	7,874	7,822	7,732	374
79	49037225100000	UPRR 3-19	19	22N	103W	WY	7,005 KB					6,630	6,620	6,620	6,575	6,470	
80	49037223000000	Celsuis Unit 16	3	16N	104W	WY	7,752 KB	2,930	2,915	2,755	2,690	2,690	2,690	2,690	2,600	2,490	200
81	49037232150000	UPRR Iron Duke 2-7	7	22N	103W	WY	7,289 KB					7,600	7,590	7,590	7,550	7,435	
82	49037215610000	Energetics 43-30	30	22N	103W	WY	7,302 KB					6,595	6,575	6,575	6,532	6,430	
83	49037226760000	Luff Federal H-18	18	22N	103W	WY	7,013 KB					7,110	7,090	7,090	7,050	6,940	
84	49037228950000	Aztec Essex 1-8	8	24N	103W	WY	7,298 KB	12,025	11,949	11,732	11,673	11,448	11,418	11,418	11,359	11,260	413
85	49037224740000	Terra 10-5	5	22N	103W	WY	6,968 KB					7,390	7,370	7,370	7,330	7,210	
86	49037215490000	Wexpro MFS-Fed 14-2	14	19N	104W	WY	6,317 KB	2,960	2,920	2,758	2,692	2,495	2,495	2,495	2,468	2,390	302
87	49037219810000	Helmerich & Payne Inc	2	13N	104W	WY	7,566 KB	9,806	9,787	9,661	9,604	9,550	9,550	9,550	9,486	9,395	209
88	49037214180000	Great Western 3-11	11	15N	104W	WY	7,611 KB	4,064	4,029	3,902	3,842	3,729	3,729	3,729	3,700	3,628	214
89	49037211390000	Elf McBride 33-32	32	24N	103W	WY	7,098 KB	9,698	9,633	9,436	9,373	9,140	9,126	9,126	9,084	9,032	341
90	49037232060000	UPRR So. Baxter 18	13	17N	104W	WY	8,307 KB	3,592	3,542	3,395	3,327	3,197	3,197	3,197	3,165	3,092	235
91	49037225350000	UPRR Leucite Hill 4-33 3	33	22N	103W	WY	7,333 KB	6,795	6,757	6,579	6,516	6,290	6,290	6,290	6,250	6,145	371
92	49037232160000	UPRR Invincible 2-14	13	20N	104W	WY	6,488 KB	3,680	3,639	3,470	3,402	3,209	3,209	3,209	3,168	3,075	327
93	49037223320000	Ensource 2-31	31	15N	103W	WY	7,181 KB	5,160	5,129	5,025	4,952	4,860	4,860	4,860	4,795	4,728	224
94	49037214250000	Woods Packsaddle 1	24	25N	103W	WY	7,652 KB	14,520	14,450	14,254	14,177	13,925	13,925	13,925	13,871	13,777	400
95	49037220220000	Resources Airport 1-16	16	19N	103W	WY	6,462 KB	3,435	3,385	3,230	3,160	2,960	2,960	2,960	2,932	2,857	303

Table 1. Well data showing depths to selected stratigraphic horizons within the Thermopolis Shale, Mowry Shale, and Frontier Formation in the Southwestern Wyoming Province, and thicknesses (column FT) of the Frontier Formation.—Continued

[ELEV, elevation of Kelly bushing (KB), ground level (GR), or drill floor (DF) in feet above mean sea level. Values in all but the last column are depths, in feet; last column is thickness, in feet. Abbreviations used: TM, top of the Thermopolis Shale or in some cases the Dakota Sandstone; SH, top of the Shell Creek Shale; ML, top of the lower Mowry Shale (blue interval on pls. 1–4); MU, top of the Mowry Shale (purple interval on pls. 1–4); BF, top of the Belle Fourche Member over most of the area but includes the lower part of the Chalk Creek in the thrust belt (base of Stands, 1999, Chalk Creek sequence boundary); CC, top of the Chalk Creek Member of the Frontier; AH, top of the Allen Hollow Shale Member of the Frontier; OE, combined tops of the Oyster Ridge Sandstone and Emigrant Gap Members, and includes any shoreface sandstones associated with the Dry Hollow Member of the Frontier in the Washakie Basin; DW, combined tops of the Dry Hollow and Wall Creek Members of the Frontier Formation; FT, Frontier thickness from top of DW to top of MU. Blank cells indicate no data. Locations of data points are shown in figure 5.]

Map no.	API number	Well name	Section	Township	Range	State	ELEV	TM	SH	ML	MU	BF	CC	AH	OE	DW	FT	
96	49037220380000	Luff Amoco-Champlin D-25	25	22N	103W	WY	7,271	KB	7,692	7,646	7,478	7,387	7,150	7,150	7,150	7,100	6,961	426
97	49037214500000	Energy Reserve Kenai Mtn	10	12N	103W	WY	9,390	KB	13,633	13,610	13,508	13,445	13,400	13,400	13,400	13,310	13,212	233
98	49037219060000	Smokey Federal 44-2	2	20N	103W	WY	7,178	GR	5,944	5,910	5,750	5,687	5,460	5,460	5,460	5,420	5,308	379
99	49037205860000	Exxon Salt Wells 1	14	14N	103W	WY	7,775	KB	7,063	7,028	6,928	6,867	6,772	6,772	6,772	6,695	6,610	257
100	49037600520000	Texas Oil & Gas Hague Hill 1	8	22N	102W	WY	7,057	GR	9,062	9,012	8,830	8,768	8,520	8,520	8,520	8,482	8,345	423
101	49037215280000	Marathon (Husky) 6-25	25	19N	103W	WY	6,552	KB	3,695	3,654	3,500	3,433	3,242	3,242	3,242	3,210	3,160	273
102	49037228890000	Daube Federal 1-6	6	20N	102W	WY	6,789	KB	6,078	6,041	5,880	5,820	5,600	5,600	5,600	5,550	5,450	370
103	49037218390000	Davis Buccaner 1	23	26N	102W	WY	7,346	KB	17,696	17,623	17,425	17,342	17,027	17,027	17,027	17,007	16,951	391
104	49037215130000	Woods Steamboat Mtn 3	34	24N	102W	WY	7,528	KB	12,699	12,630	12,450	12,375	12,170	12,150	12,150	12,080	11,990	385
105	49037215310000	Houston Fed 23-4	4	17N	102W	WY	7,257	KB	5,580	5,545	5,405	5,342	5,170	5,170	5,170	5,130	5,070	272
106	49037219040000	Woods Freightier 13-1	13	24N	102W	WY	7,610	KB	14,283	14,220	14,033	13,960	13,720	13,708	13,708	13,660	13,585	375
107	49037219660000	Davis Musketeer 1	8	26N	101W	WY	7,543	KB	19,222	19,143	18,949	18,850	18,562	18,562	18,562	18,530	18,390	460
108	49037206740000	Chambers 16-14-102 W498	16	14N	102W	WY	7,413	GR	8,455	8,438	8,324	8,258	8,137	8,137	8,137	8,058	7,942	316
109	49037207370000	Davis 1 SE Snowshoe	3	20N	102W	WY	6,959	GR	6,995	6,966	6,813	6,750	6,525	6,525	6,525	6,495	6,390	360
110	49037209700000	Luff 2-1	1	17N	102W	WY	6,872	KB	6,896	6,874	6,733	6,666	6,480	6,480	6,480	6,444	6,348	318
111	49037220320000	Woods Treasure 4	28	24N	101W	WY	7,544	KB	14,487	14,425	14,258	14,185	13,890	13,880	13,880	13,840	13,770	415
112	05081063820000	Texaco Diamond 1-X	36	12N	102W	CO	7,284	GR		14,614	14,512	14,452	14,438	14,438	14,438	14,326	14,265	187
113	49037227930000	True Oil Beard Fed 24-4A	4	20N	101W	WY	6,761	GR	8,373	8,350	8,200	8,147	7,920	7,898	7,898	7,870	7,800	347
114	49037205990000	Grynburg 42X-16	16	14N	101W	WY	7,665	KB	11,874	11,850	11,737	11,680	11,532	11,532	11,532	11,447	11,312	368
115	49037220680000	Davis Sidewinder 1	35	19N	101W	WY	6,877	KB	7,115	7,020	6,930	6,870	6,617	6,617	6,617	6,584	6,530	340
116	05081069780000	Marathon Sparks Ridge 2	4	11N	101W	CO	7,012	GR		12,788	12,662	12,598	12,588	12,588	12,588	12,463	12,412	186
117	49037223340000	Champlin Brady 36N	2	16N	101W	WY	7,121	KB	10,822	10,805	10,660	10,605	10,367	10,367	10,367	10,343	10,260	345
118	49037217770000	Amoco 259 B-1	1	20N	101W	WY	7,018	KB	9,669	9,647	9,505	9,436	9,210	9,188	9,188	9,140	9,078	358
119	49037219550000	Woods Saddlebag 22-1	22	24N	100W	WY	7,059	KB	16,310	16,246	16,083	16,010	15,695	15,695	15,695	15,650	15,550	460
120	49037228910000	Duncan 1-9	9	17N	100W	WY	6,841	KB	10,995	10,965	10,830	10,770	10,530	10,530	10,530	10,530	10,427	343
121	05081062890000	Samedan Talamantes 1-XA	17	11N	100W	CO	6,444	KB		14,109	14,000	13,942	13,932	13,932	13,932	13,806	13,746	196
122	49037051380001	Mtn Fuel Kinney unit 2	18	13N	99W	WY	7,295	KB		14,007	13,895	13,838	13,680	13,680	13,680	13,564	13,484	354
123	49037216710000	Texaco Table Rock 44	18	19N	97W	WY	6,822	GR		14,988	14,850	14,780	14,500	14,500	14,500	14,467	14,417	363
124	49013216600000	Lockridge Bison 30	17	27N	95W	WY	7,053	KB	2,203	2,113	2,003	1,912	1,360	1,360	1,360	1,290	995	917
125	49037225780000	Amoco Frewen Deep 1	13	19N	95W	WY	6,937	KB	18,844	18,842	18,725	18,662	18,348	18,348	18,348	18,300	18,255	407
126	49013210980000	Exxon Jade	17	28N	93W	WY	8,074	KB	6,745	6,650	6,470	6,353	5,760	5,760	5,760	5,660	5,422	931
127	05081066080000	Arco McIntyre 1-3	3	7N	94W	CO	6,658	KB		11,850	11,765	11,720	11,565	11,565	11,565	11,515	11,495	225

Table 1. Well data showing depths to selected stratigraphic horizons within the Thermopolis Shale, Mowry Shale, and Frontier Formation in the Southwestern Wyoming Province, and thicknesses (column FT) of the Frontier Formation.—Continued

[ELEV, elevation of Kelly bushing (KB), ground level (GR), or drill floor (DF) in feet above mean sea level. Values in all but the last column are depths, in feet; last column is thickness, in feet. Abbreviations used: TM, top of the Thermopolis Shale or in some cases the Dakota Sandstone; SH, top of the Shell Creek Shale; ML, top of the lower Mowry Shale (blue interval on pls. 1–4); MU, top of the Mowry Shale (purple interval on pls. 1–4); BF, top of the Belle Fourche Member over most of the area but includes the lower part of the Chalk Creek in the thrust belt (base of Stands, 1999, Chalk Creek sequence boundary); CC, top of the Chalk Creek Member of the Frontier; AH, top of the Allen Hollow Shale Member of the Frontier; OE, combined tops of the Oyster Ridge Sandstone and Emigrant Gap Members, and includes any shoreface sandstones associated with the Dry Hollow Member of the Frontier in the Washakie Basin; DW, combined tops of the Dry Hollow and Wall Creek Members of the Frontier Formation; FT, Frontier thickness from top of DW to top of MU. Blank cells indicate no data. Locations of data points are shown in figure 5.]

Map no.	API number	Well name	Section	Township	Range	State	ELEV	TM	SH	ML	MU	BF	CC	AH	OE	DW	FT
128	05081064130000	Kemmerer Coal 23-2	23	10N	94W	CO	6,747	GR	17,290	17,120	17,072	16,905	16,905	16,905	16,845	16,823	249
129	49007212490000	Amoco Echo Sps Deep	21	18N	93W	WY	6,793	KB	18,095	17,977	17,925	17,600	17,600	17,600	17,545	17,470	455
130	49013217230000	Key Production Co	8	28N	92W	WY	6,654	KB	5,850	5,800	5,573	5,457	4,840	4,840	4,840	4,730	955
131	05081066700000	UPRR Weco-Kleit 23	29	7N	92W	CO	6,564	KB	9,216	9,154	9,113	8,862	8,862	8,862	8,845	8,800	313
132	49013217610000	Davis Green Mtn Fed 1	30	28N	91W	WY	8,374	KB	6,838	6,799	6,595	6,474	5,792	5,792	5,792	5,680	1,057
133	49037223090000	Hunt Fed 1-6	6	26N	90W	WY	7,410	KB	10,600	10,500	10,303	10,253	9,670	9,670	9,670	9,608	953
134	49007203910000	Texas Fed Y 1	14	15N	91W	WY	6,779	KB	8,274	8,180	8,130	7,770	7,770	7,770	7,730	7,640	490
135	49007206490000	Texas Amer. Oil TAO 1-24	24	16N	91W	WY	7,148	KB				7,650	7,650	7,650	7,600	7,480	
136	49013213780000	Sohio Fed 2-B	2	27N	90W	WY	7,083	KB	10,267	10,203	10,067	9,959	9,325	9,325	9,325	8,975	984
137	49037217620000	Florida Explor. Able Ck 1-23	23	26N	90W	WY	6,857	KB		5,762	5,560	5,505	4,810	4,810	4,810	4,690	1,145
138	49007210640000	Amoco Wertz ABC	7	26N	89W	WY	6,825	KB	3,588	3,529	3,404	3,307	2,742	2,742	2,742	2,345	962
139	49007051030000	McCulloch State Tuttle 1	27	17N	90W	WY	7,576	KB				6,920	6,920	6,920	6,880	6,742	
140	49007200340000	Tenneco 1 USA Trowbridge	26	19N	90W	WY	7,174	KB	8,355	8,324	8,200	8,162	7,785	7,785	7,785	7,438	724
141	05081065240000	Coors Winder 1-26	26	4N	90W	CO	7,817	KB		5,915	5,828	5,800	5,520	5,520	5,520	5,412	388
142	49007210250000	Amoco Bailey Dome 10	21	26N	89W	WY	6,612	KB	4,580	4,525	4,387	4,283	3,719	3,719	3,719	3,608	973
143	49007207290000	Farmers Union Fed 7-14	14	25N	89W	WY	6,533	KB	2,802	2,749	2,626	2,540	1,979	1,979	1,979	1,897	950
144	49007052150000	McCulloch 3 Bence Fed	26	19N	89W	WY	7,628	DF		5,552	5,433	5,392	4,990	4,990	4,990	4,920	552
145	49007207780000	Wold 1-31	31	25N	88W	WY	6,517	KB	2,853	2,807	2,690	2,610	2,040	2,040	2,040	1,975	948
146	49007206260000	Chancellor 234	29	24N	88W	WY	6,516	KB	1,590	1,559	1,445	1,378	1,000	1,000	1,000	888	798
147	49007206980000	Solar PLC-Rim-Fed 1	10	19N	88W	WY	7,209	KB	4,084	4,054	3,930	3,890	3,450	3,450	3,450	3,410	775
148	49007210590000	Amoco Mahoney 1-30	30	26N	87W	WY	7,059	KB	2,270	2,030	1,887	1,810	1,260	1,260	1,260	1,245	865
149	49007205610000	Solar UPRR 1	35	20N	88W	WY	7,263	KB	3,800	3,800	3,660	3,612	3,190	3,190	3,190	3,160	732
150	49007213740000	Sinclair Fed 11-24	24	20N	88W	WY	7,309	KB	5,290	5,290	5,180	5,130	4,735	4,735	4,735	4,670	750
151	05107060630000	Southland Royalty Dry Ck 1	22	5N	88W	CO	7,238	GR		6,950	6,890	6,850	6,590	6,590	6,590	6,540	340
152	49007214550000	Sinclair 16-16	16	21N	86W	WY	6,592	KB	1,680	1,680	1,552	1,515	1,070	1,070	1,070	1,015	815
153	05103059190000	Texas Gov Cheney 1	25	3N	87W	CO	8,556	DF		3,725	3,650	3,623	3,340	3,340	3,340	3,295	373
154	05107061190000	Texas Gas Tow Ck Fed 5-5	5	6N	86W	CO	6,931	KB		4,240	4,160	4,136	3,900	3,900	3,900	3,845	346
155	05107060370000	Benson Oak Ck 12-2	2	3N	86W	CO	8,825	KB		5,550	5,475	5,450	5,170	5,170	5,170	5,130	370
156	05107051970000	Daubes Pastouris 1	23	3N	85W	CO	8,417	GR		1,335	1,262	1,230	920	920	920	893	390

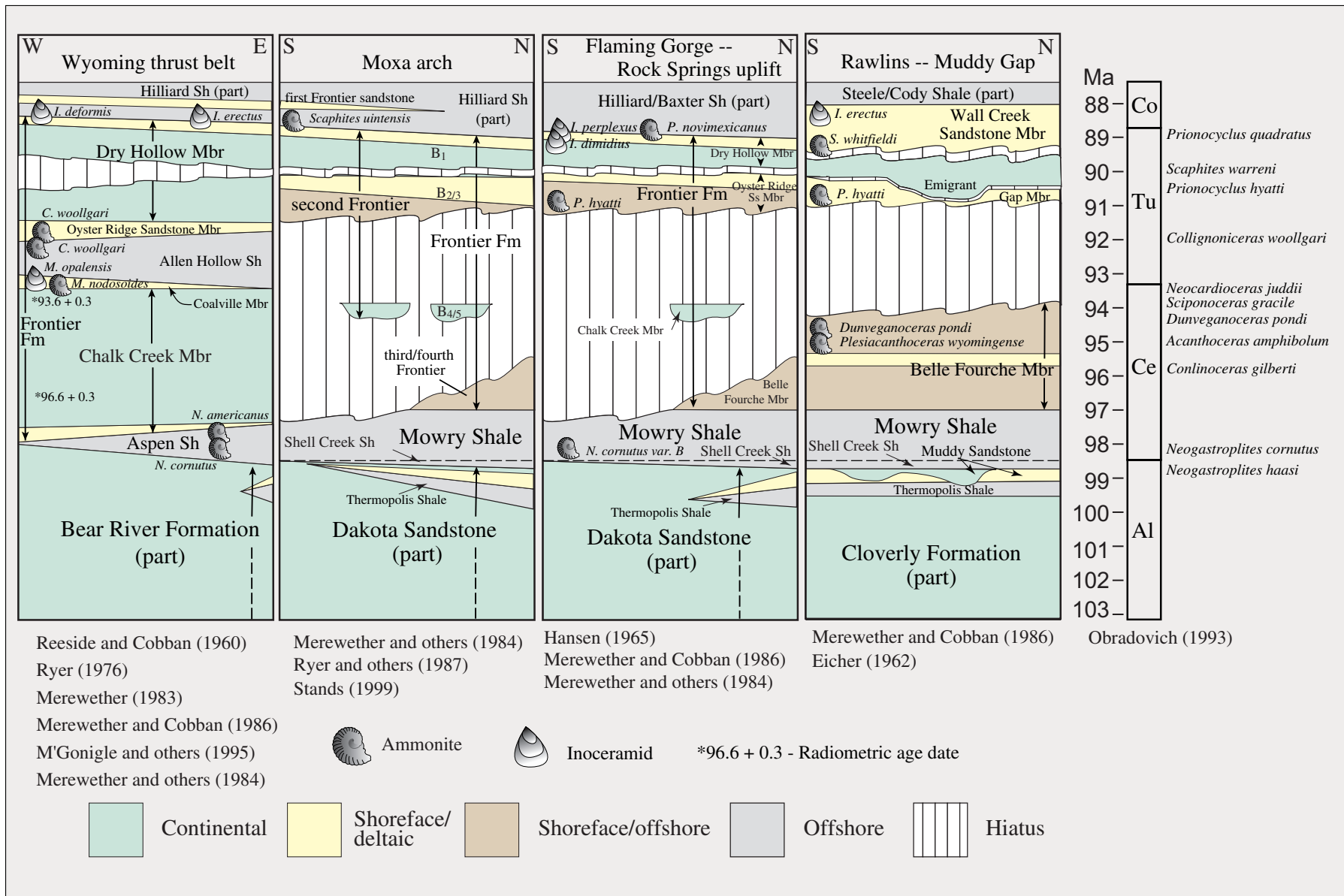


Figure 2. Columnar sections of the Mowry Composite Total Petroleum System for three locations within the Southwestern Wyoming Province and one for the Wyoming thrust belt located west of the province. Generalized depositional environments are shown. Stratigraphic names are based on successions observed in outcrops; subsurface equivalent names are shown only for the Moxa arch area. B1–B5, benches within the second Frontier; B1, Dry Hollow Member; B2/3, Oyster Ridge Member; B4/5, Chalk Creek Member; third and fourth Frontier, equivalent to the Belle Fourche and lower Chalk Creek Members.

Depositional Environments

Three generalized depositional environments—marine, shoreface/deltaic, and continental—were identified based on interpretations of lithology, trace fossils, and sedimentary structures described in core and outcrop. The interpretation of environments determined from cores were used to help map units in the cross sections by comparing cores to their corresponding geophysical logs (pls. 1–4). Marine shale is generally the easiest lithology to identify and correlate because of a high clay content and good lateral continuity. Shoreface and deltaic deposits generally show an upward decrease in gamma-ray values, consist mainly of sandstone, and also have good lateral continuity allowing reasonably good correlations in the subsurface. On geophysical logs from uncored wells, shoreface and deltaic sandstones were interpreted mainly by using a minimum gamma-ray value, but a standard American Petroleum Institute (API) cutoff was not applied to all logs because there was not a one-to-one correspondence of sandstone to a specific API value when the value was compared to lithologies exhibited in cores. Therefore, each log was evaluated separately to estimate the thickness of sandstone; an average shale line and maximum sandstone line were estimated and sandstone was then interpreted at 25 percent above the maximum sand line. The continental strata were the most difficult to identify with confidence unless core was available because of the varied gamma-ray responses that are characteristic of these deposits. Continental units may overlap somewhat with the other two environments.

Marine

Marine rocks include isolated thin sandstone beds, interbedded burrowed to laminated sandstone and shale, siltstone, and shale. Marine shale is generally characterized by high gamma-ray and low resistivity signatures on geophysical logs. Extremely high gamma-ray signatures in combination with low resistivity or high conductivity are interpreted as bentonite beds, which are important marker horizons.

Shoreface and Deltaic Deposits

Shoreface and deltaic strata are defined in this study as sediments that accumulated between the point of highest wave action at high tide (foreshore) and storm wavebase in or adjacent to a completely open-water marine setting. These deposits are recognized on the geophysical logs as having decreasing-upward gamma-ray signatures, which are related to coarsening-upward successions in cores and outcrop, and normally these log signatures can be traced between wells that are from several to tens of miles apart. Rocks identified as shoreface sandstone on cross sections (pl. 1–4) may include some marine or continental rocks because of the uncertainty that typically

accompanies interpreting log signatures. In core, the dominant facies observed in this environment is burrowed to bioturbated sandstone. Sedimentary structures observed in cores include low- to high-angle cross lamination. Low-angle lamination is interpreted as lower shoreface, hummocky cross stratification when it is indicated by the stratigraphic context; otherwise it is shown as horizontal lamination in the core description. Higher angle cross laminations are interpreted as undifferentiated cross stratification and can be indicative of several environments, including upper shoreface.

Continental (Coastal Plain/Estuarine)

Continental strata are defined as rocks that were deposited near or above the landward limit of marine conditions and have either fresh or brackish water (tidal) influence. This environment is characterized by fluctuating gamma-ray signatures on geophysical logs and by sandstones that have increasing-upward gamma-ray signatures related to fining-upward successions in core and outcrop. In core, rock types consist of interbedded sandstone, mudrock, carbonaceous shale, and coal. Sandstones are generally cross stratified, rippled, or convoluted. Cross-stratified sandstone units are difficult to distinguish from upper shoreface, fluvial, and estuarine depositional environments. A transition in the cores from dominantly coarsening-upward successions topped by fine-grained bioturbated sandstone to fining-upward successions with basal medium- and coarse-grained cross-stratified sandstone is interpreted to mark the change from shoreface to continental rocks. An interpretation of tidal influence is added to the fining-upward successions based primarily on the presence of trace fossils and flaser-wavy-lenticular bedding. Mudrocks with abundant carbonaceous fragments or roots are also diagnostic of continental strata.

Stratigraphy

Dakota Sandstone and Cloverly Formation (Lower Cretaceous)

Predominantly fluvial strata lying below marine shale of the Thermopolis Shale, or in some cases the Shell Creek Shale, and above variegated beds of the underlying Morrison Formation were assigned to the Dakota Sandstone, based on outcrop mapping in the Flaming Gorge area near the south plunge of the Moxa arch (Hansen, 1965). In subsurface sections these rocks are also referred to as Dakota in the southern parts of the Moxa arch (Ryer and others, 1987) or to the Muddy Sandstone Member of the Thermopolis Shale by some investigators (Walker, 1992). The unit changes facies from dominantly fluvial sandstone in the southern parts of the Moxa

arch (well A–1 north to about well A–11, pl. 1) to dominantly nearshore marine sandstone and interbedded marine rocks of the Thermopolis Shale in the northern parts of the Moxa arch (pl. 1) (Ryer and others, 1987). A similar facies relationship was observed in the Rock Springs uplift. Fluvial rocks dominate facies in what we referred to as the Dakota in the southern part of the Rock Springs uplift (well C–1 north to about well C–7, pl. 3) and then change facies to interbedded nearshore marine sandstone and marine shale farther north (pl. 3). East of the Rock Springs uplift, toward the east side of the Great Divide Basin (fig. 1), the name Cloverly is used instead of the lower part of the Dakota Sandstone (pl. 4).

Thermopolis Shale (Lower Cretaceous)

The Thermopolis Shale is applied to a succession of marine shale, nearshore marine sandstone, and continental deposits (incised-valley fill) in the Wind River and Bighorn Basins (Dolson and others, 1991; U.S. Geological Survey, 2004). The name was extended to strata in the northeastern part of the Greater Green River Basin by Eicher (1962) and subsequently has been in use by the petroleum industry on the Moxa arch (for example, see Walker, 1992). Also on the Moxa arch, a tongue of the Thermopolis has been referred to as the G shale of the Dakota Sandstone by Ryer and others (1987).

In the northeastern part of the Southwestern Wyoming Province, the Muddy Sandstone Member of the Thermopolis Shale can be recognized on outcrop (Reynolds, 1968) and in the subsurface as either a thin, decreasing upward gamma-ray response or a thicker, increasing-upward gamma-ray response (pl. 4).

Shell Creek Shale (Lower Cretaceous)

The Shell Creek Shale lies between the Thermopolis Shale (Muddy Sandstone Member where present) and the Mowry Shale (fig. 2). The lower contact of the formation is placed at a high gamma-ray response on geophysical logs 1 to 40 ft above the highest sandstone of the Muddy (see pl. 4). This high gamma-ray response can be traced with some confidence around the province and provides a mappable subsurface contact between the Thermopolis and Shell Creek Shales where the Muddy Sandstone Member is absent (pls. 1–3). The Shell Creek is thickest on the northern Moxa arch (pls. 1 and 2).

The name Shell Creek Shale was applied in the Big Horn Basin of north-central Wyoming by Eicher (1960), who later (Eicher, 1962) traced the unit into the Dutton Basin, north of our study area (sec. 18, T. 33 N., R. 89 W.) but interpreted it to pinch out before it reaches the Greater Green River Basin. Reynolds (1968) mapped a shale unit between the Muddy and the Mowry as the upper shale member of the Thermopolis in the Muddy Gap area (fig. 1), which corresponds to the unit we call Shell Creek in this report. Ryer and others (1987, their

fig. 1) show the Shell Creek to be present on the Moxa arch but also refer to the unit as the lower, nonsiliceous member of the Mowry Shale (Ryer and others, 1987, their fig. 12). Walker (1992) correlated the Shell Creek along the Moxa arch, and this nomenclature is apparently derived from an unpublished work by Research Planning Institute (for example, see Miller and others, 1992, p. 302). The Shell Creek terminology is also shown by Dolson and others (1991) for part of the Greater Green River Basin.

The character of the Shell Creek Shale is best seen on cross section B–B' (pl. 2). In the Rock Springs area, only a thin remnant of this unit is interpreted between the basal Mowry marker bed and the top of the first well-developed sandstone of the Muddy below. Part of this unit could represent lithologies of either brackish water or freshwater origin within the Muddy.

Mowry Shale (Upper Cretaceous)

The name Mowry Shale is extended into the area of our study from exposures in the Powder River Basin and across the intervening areas (U.S. Geological Survey, 2004). In the subsurface of the Southwestern Wyoming Province, the Mowry is recognized as a high resistivity zone on geophysical logs; for example, see well A–2 to A–11 on plate 1. This distinctive signature reflects the highly siliceous character of the shales and the presence of numerous interbedded thin bentonite beds. However, determining the exact positions of both the upper and lower contacts can be problematic. Nixon (1973) arbitrarily placed the base at a persistent high gamma-ray spike within the lower part of the high-resistivity shale section that characterizes the Mowry. The top of the unit is typically placed at the top of the Clay Spur Bentonite Bed (Nixon, 1973; Burtner and Warner, 1984). The Clay Spur has been traced into the subsurface of the Powder and Wind River Basins and is present at the top of a unique log signature consisting of an increasing-upward natural gamma count (Nixon, 1973, his fig. 2; Bhattacharya and Willis, 2001, their figure 2). We identified two mappable subunits within the Mowry that are bounded by traceable bentonite beds; these subunits are colored purple and blue on the cross sections.

In the northeastern part of the Southwestern Wyoming Province, the top of the Mowry Shale was placed at the top of a 3- to 5-ft-thick bentonite that can be recognized on outcrop and was placed at a high gamma-ray spike that is interpreted to be the Clay Spur just above the increasing-upward gamma-ray signature in the subsurface (Merewether and Cobban, 1972). In the present study, these markers were then traced southward along the eastern margin of the province south of Rawlins, Wyoming, and traced westward across the Washakie Basin (key wells include Towbridge, Amoco Echo Springs deep, and Amoco Frewen deep; fig. 1) to the Rock Springs uplift and beyond to the western margin of the province.

On the east side of the Rock Springs uplift, the top of the Mowry is placed at a prominent high gamma-ray spike that

is near the base of a prominent resistivity/conductivity spike that typically has been used as the contact of the Mowry (see Nixon, 1973, and Curry, 1986). This resistivity/conductivity spike, however, does not match a distinct lithologic contact as recorded by the gamma-ray log, and so was not used by us as the contact.

In the western part of the Greater Green River Basin, the base of the Mowry was placed at the base of a high gamma-ray interval, which was labeled M400 (Miller and others, 1992, for example, p. 258). This same gamma-ray spike is the B2 horizon of Stands (1999). The top of the Mowry is consistently placed at a conductivity spike that correlates, in places, with a high gamma-ray spike shown by Miller and others (1992). This conductivity spike was mapped by Stands (1999) as the Km700 marker bed, which he shows to be about at the top of the Mowry. Curry (1986, his fig. 2, well 3) also interprets this conductivity spike to be the top of the Mowry. We interpret the high gamma-ray spike just above the Km700 to be approximately equivalent to the Clay Spur Bentonite Bed and use it as our contact. [Note: Map units B3 of Stands (1999) is close to (less than 50 ft above) the base of the Shell Creek; B2 of Stands is at the base of our blue unit (that is, base of the Mowry); B1 of Stands is at the top of the blue unit; and Km700 of Stands is close to top of the purple unit (that is, the top of the Mowry).]

Frontier Formation (Upper Cretaceous)

The correlation diagram (fig. 2) shows the age control and interpretations of the stratigraphic correlations of units within the Frontier Formation in the Southwestern Wyoming Province. On the northeast margin of the province, the Frontier ranges from about 600 ft to as much as 1,000 ft thick (fig. 3) and is divided into three members: in ascending order, the Belle Fourche, the Emigrant Gap (formerly called the unnamed member), and the Wall Creek Sandstone Members (pl. 4) (Merewether, 1983; Mieras, 1993). In the Rock Springs uplift area to the west, we correlate the Emigrant Gap Member with the Oyster Ridge Sandstone Member, and the Dry Hollow Member, in part, with the Wall Creek Sandstone Member (fig. 2). Others have made this correlation as well (for example, Merewether and Cobban, 1986).

On outcrops in the Wyoming thrust belt (fig. 1), the Frontier Formation consists of five members (fig. 2): in ascending order, the Chalk Creek, Coalville, Allen Hollow, Oyster Ridge Sandstone, and Dry Hollow Members (Hale, 1960; M'Gonigle and others, 1995). These members are exposed on the hanging walls of imbricate thrusts in eastern Idaho, western Wyoming, and northern Utah (fig. 1). In the subsurface in the westernmost part of the Southwestern Wyoming Province, the Frontier is informally divided, in ascending order, into the fourth through the first Frontier. The second Frontier is further divided into benches 5 through 1 (fig. 2, Moxa arch column).

The formation thickness is about 4,000 ft (not includ-

ing the first Frontier) on the hanging wall of the Hogsback thrust, but thins to about 250 ft thick in the footwall (fig. 3). The rapid eastward thinning of the members toward the east is mainly due to depositional thinning within the foreland basin away from the thrust belt. On the Moxa arch and Rock Springs uplift, remnants of the Chalk Creek Member are interpreted on well logs (pl. 1, wells A-13 to A-17) and in core (core E540, pl. fig. 2-1; core B326, pl. fig. 3-1; also see Hamlin, 1996, his figs. 5 and 6). The contact of the continental Chalk Creek with the underlying marine and marginal marine Belle Fourche Member of the Frontier is difficult to discern unless cores are available (pls. 1 and 2). The Allen Hollow is only preserved in the thrust belt and has been removed by erosion during the Cretaceous within the Southwestern Wyoming Province (fig. 2). The Oyster Ridge Sandstone Member is easily traced from outcrops in the Wyoming thrust belt, where the unit is dated by the presence of *Collignonicerias woollgari*, eastward into the subsurface to the western flank of the Rock Springs uplift (pl. 2) and then southward to outcrops near Flaming Gorge (pl. 3), where the unit contains the ammonite *Prionocyclus hyatti* (fig. 2). The Dry Hollow Member can also be traced in the subsurface as far east as the Rock Springs uplift (pl. 2).

There is a nomenclature change in the Frontier Formation between the Rock Springs uplift and the Rawlins uplift (fig. 2) and, because of sparse subsurface control, it is difficult to determine where best to apply the various names in the intervening area. Three wells drilled between these uplifts (Echo Springs deep, Amoco Echo Springs deep, and the Tenneco #1 USA Trowbridge, fig. 1) provide the best data to resolve which units are represented. The basal Emigrant Gap Member shoreface sandstone (pl. 4) is apparently present in all three wells based on stratigraphic position relative to underlying bentonites in the Belle Fourche Member. It should be noted, however, that the Emigrant Gap is shown by Merewether and Cobban (1972) to pinch out or to be truncated on outcrop in the Rawlins area. Its presence in those three wells would require sediment bypass along the unconformity at the base of the continental strata of the Emigrant Gap (pl. 4). We interpret the Emigrant Gap Member to be the approximate equivalent of shoreface sandstones of the Oyster Ridge Sandstone Member and (or) lower part of the Dry Hollow Member of the Frontier Formation in the western part of the province. The Wall Creek Member (pl. 4) appears to grade westward approximately into the upper part of the Dry Hollow Member and lower part of the Baxter Shale on the Rock Springs uplift.

The top of the Frontier is generally placed at the top of the highest sandstone above which lies the thick body of marine shale of the Hilliard, Baxter, Mancos, Steele, or Cody Shales. In the La Barge area (fig. 1), the first Frontier sandstone is a recognized tongue within these shales that is well developed above the main body of the Frontier and can be identified as far east as the northern Rock Springs uplift (pl. 2). The first Frontier was not included in units isopached and shown in figure 3.

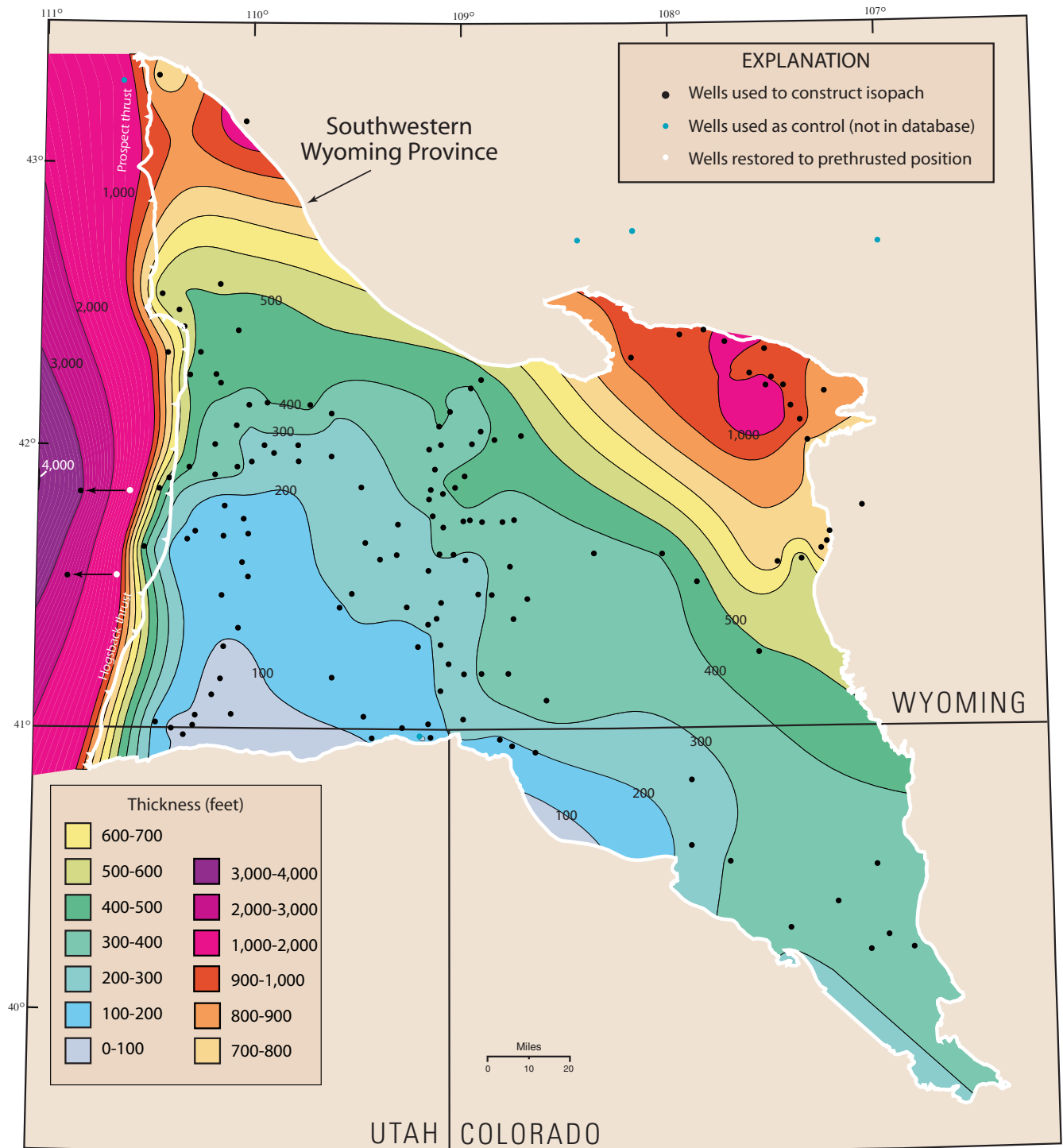


Figure 3. Isopach map of the Frontier Formation (exclusive of the first Frontier sandstone) in the Southwestern Wyoming Province.

Hilliard, Baxter, Mancos, Steele and Cody Shales (Upper Cretaceous)

The 3,000 to 5,000 ft of marine shale above the Frontier Formation (Finn and Johnson, Chapter 14, this CD-ROM) are called (1) Hilliard Shale in the Green River Basin proper and on outcrop near Flaming Gorge; (2) Baxter Shale on the Rock Springs uplift and in adjacent wells; (3) Mancos Shale in the Sand Wash Basin; (4) Steele Shale in the Washakie Basin, in most of the Great Divide Basin, and near Rawlins; and (5) Cody Shale in the northeastern part of the Great Divide Basin. In the Rawlins area, a tongue of Cody Shale, present between the Frontier and Niobrara Formations (pl. 4), has been called the unnamed calcareous unit (Merewether and Cobban, 1972; Merewether, 1973), the Sage Breaks Shale (Merewether, 1983), or a tongue of the Cody equivalent to the Niobrara (Reynolds, 1968). We show this unit as a tongue of the Cody Shale on plate 4. In the western part of the study area, the Hilliard contains the first Frontier sandstone tongue (fig. 2), which can be distinguished as a silty or sandy interval as far east as the Rock Springs uplift (pls. 2, 3).

Isopach Map of the Frontier Formation

An isopach map of the Frontier Formation (fig. 3) was constructed on the basis of our interpretations of 156 geophysical logs (fig. 4; table 1), many of which are used on the four regional cross sections (pls. 1–4). The interval thicknesses (table 1, column FT) were calculated by subtracting the depth to the top of the Dry Hollow or Wall Creek Sandstone Members (column DW in table 1) from the depth to the top of the Mowry Shale (column MU in table 1).

Six control points located outside of the Southwestern Wyoming Province were used to constrain thickness trends at the margins of the province, including three subsurface points from the Wind River Basin in Wyoming and from outcrop measurements at Dutch John and Coalville in Utah, based on Frontier thickness compilations in Roberts and Kirschbaum (1995). In addition, an average thickness (950 ft) for the Jackson, Wyoming area, was obtained from a published measured surface section by Love and others (1951), an unpublished measured surface section (E.A. Merewether, written commun., 2003), and a nearby drill hole. Two measurements from drill

holes in the Wyoming thrust belt have been palinspastically restored 12 miles west of their present locations (fig. 3), based on restorations by Royse (1993). The Coalville section was restored 37.5 miles to the west, based on DeCelles (1994). The Frontier Formation thickness data were modeled and contoured using EarthVision (Dynamic Graphics, Inc., 2002).

Structure Contour Map on Top of the Frontier Formation

The structure contour map (fig. 5) was constructed with the top of the Dry Hollow Member (second Frontier) or Wall Creek Sandstone Member of the Frontier Formation as a datum. Data used for the map included about 4,000 wells from the Petroleum Information/Dwights PetroROM well-history database (IHS Energy Group, 2001), that listed depths to the top of the Frontier. These data were modeled and contoured using EarthVision to reveal obvious anomalies represented by “bulls eyes.” Data in these areas then were either deleted or the geophysical logs were checked and the values changed. Outcrop elevations were derived digitally by intersecting lines representing the top of the Frontier (and equivalents) from digital geologic maps with a digital elevation model of the topographic surface. Selected major fault traces, also from digital geologic maps, were added to the model. In areas with little or no data, including the northern Great Divide Basin and the deep parts of the Washakie and Sand Wash Basins, structure contours were extrapolated by using the structure contour map of the top of the Mesaverde Group (Johnson and Finn, Chapter 8, this CD-ROM) and an inferred thickness from the top of the Mesaverde Group to the top of the Frontier derived from a regional isopach map.

The top of the Frontier picked by the authors and used in the isopach map (DW in table 1) was interpreted 2 years after the structure map was created and is not used in its construction. However, when locations and calculated elevations of the top of the Frontier from table 1 were plotted on the structure map, the values were consistent with the map. It should be noted that this structure map was used to create the depth map to the top of the Frontier in Kirschbaum and Roberts (Chapter 5, this CD-ROM).



Figure 4. Index map of the Southwestern Wyoming Province showing location of data points in stratigraphic database (table 1) used in construction of isopach map (fig. 3). Numbered locations are sorted first by longitude, starting in the west, and then by latitude, beginning at the north.

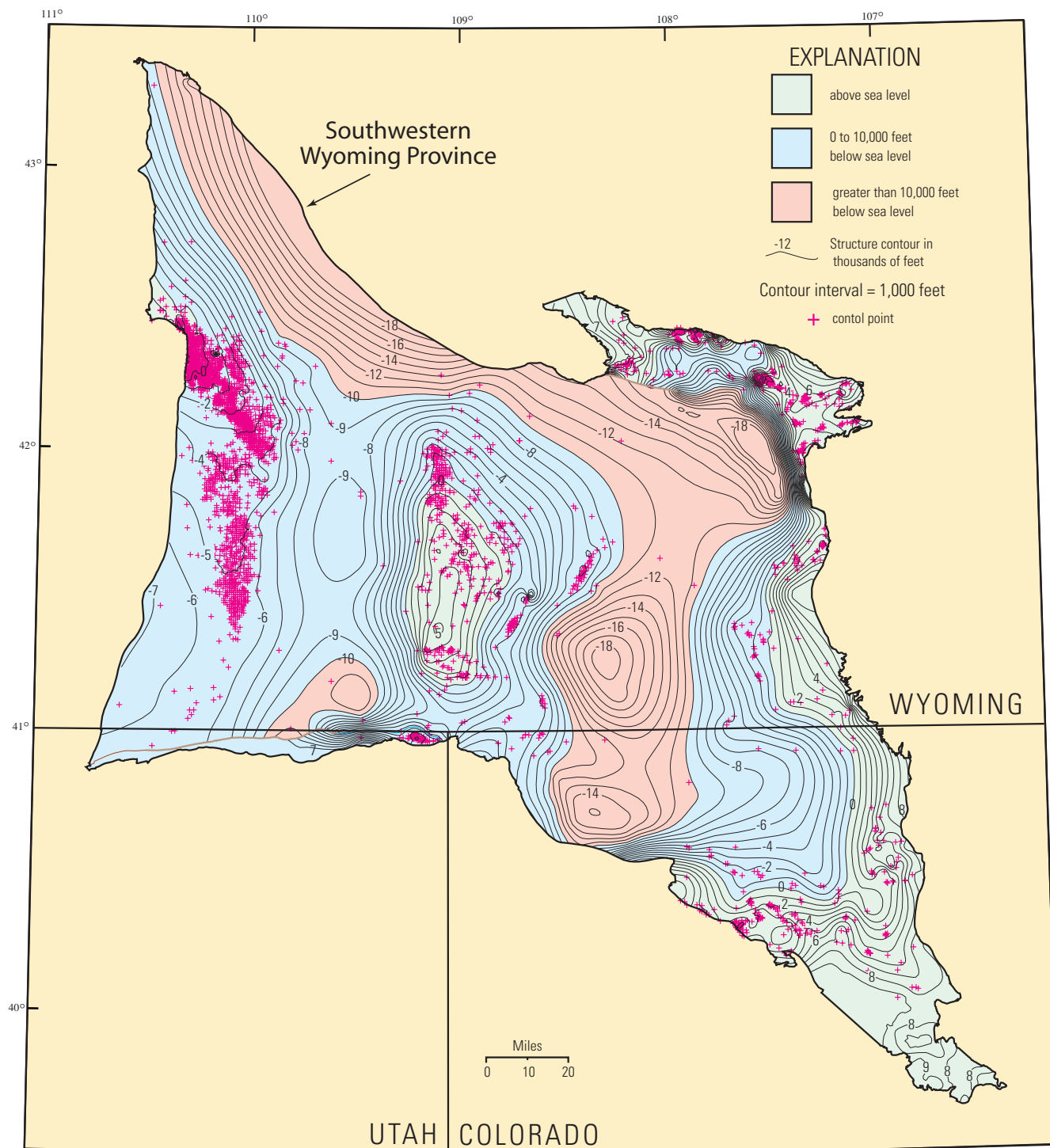


Figure 5. Structure contour map on top of the Frontier Formation (exclusive of the first Frontier sandstone) in the Southwestern Wyoming Province. Data are from about 4,000 wells listed in the Petroleum Information/Dwights PetroROM well-history database (IHS Energy Group, 2001). See text for methods used in constructing map.

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Click on image below to bring up high-resolution image of plate figure 1–1.

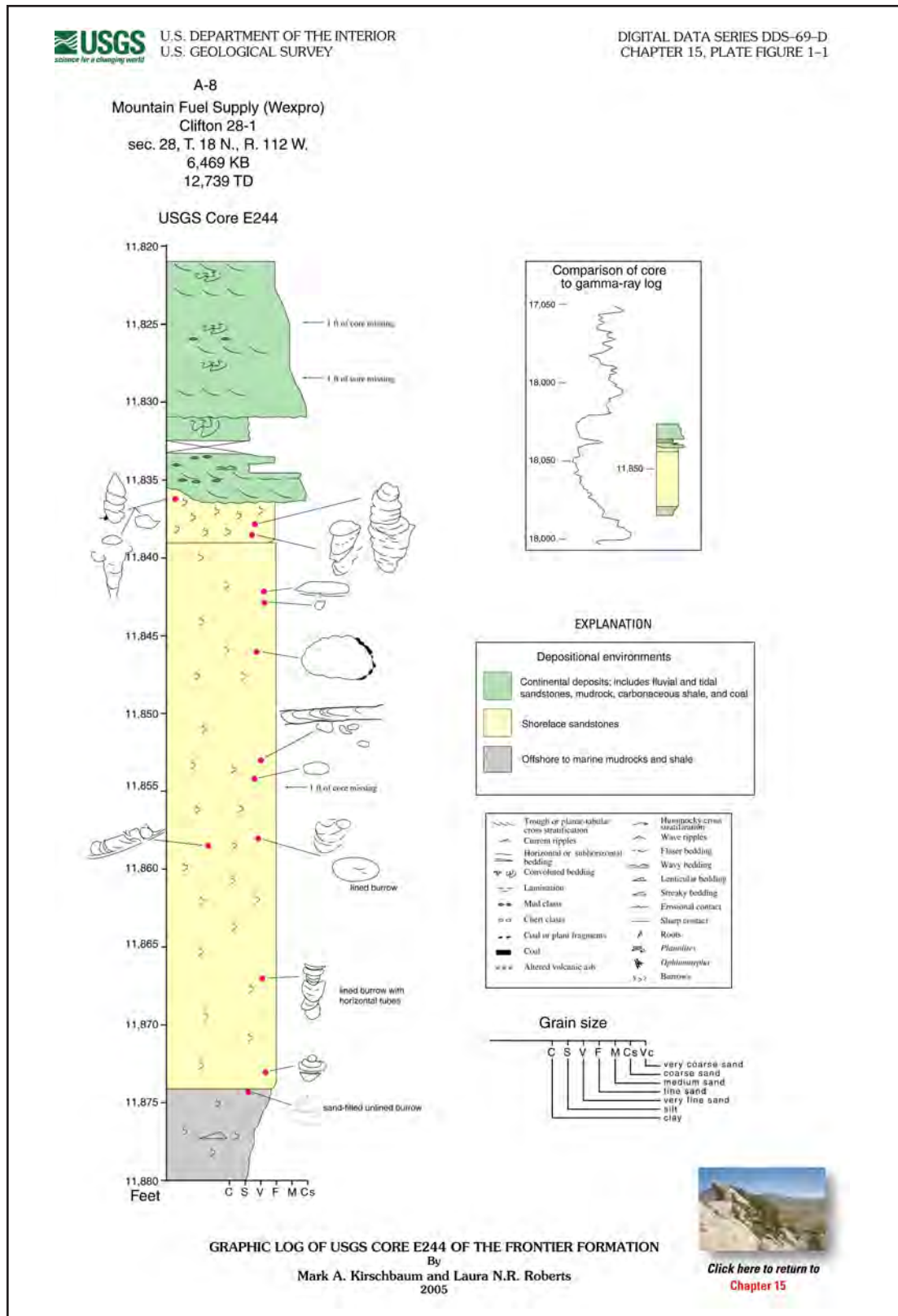


Plate figure 1-1. Graphic log of USGS core E244 of the Frontier Formation. The described core is in the depth interval 11,821–11,880 feet. Abbreviations: KB, Kelly bushing; TD, total depth.

Click on image below to bring up high-resolution image of plate figure 1–2.

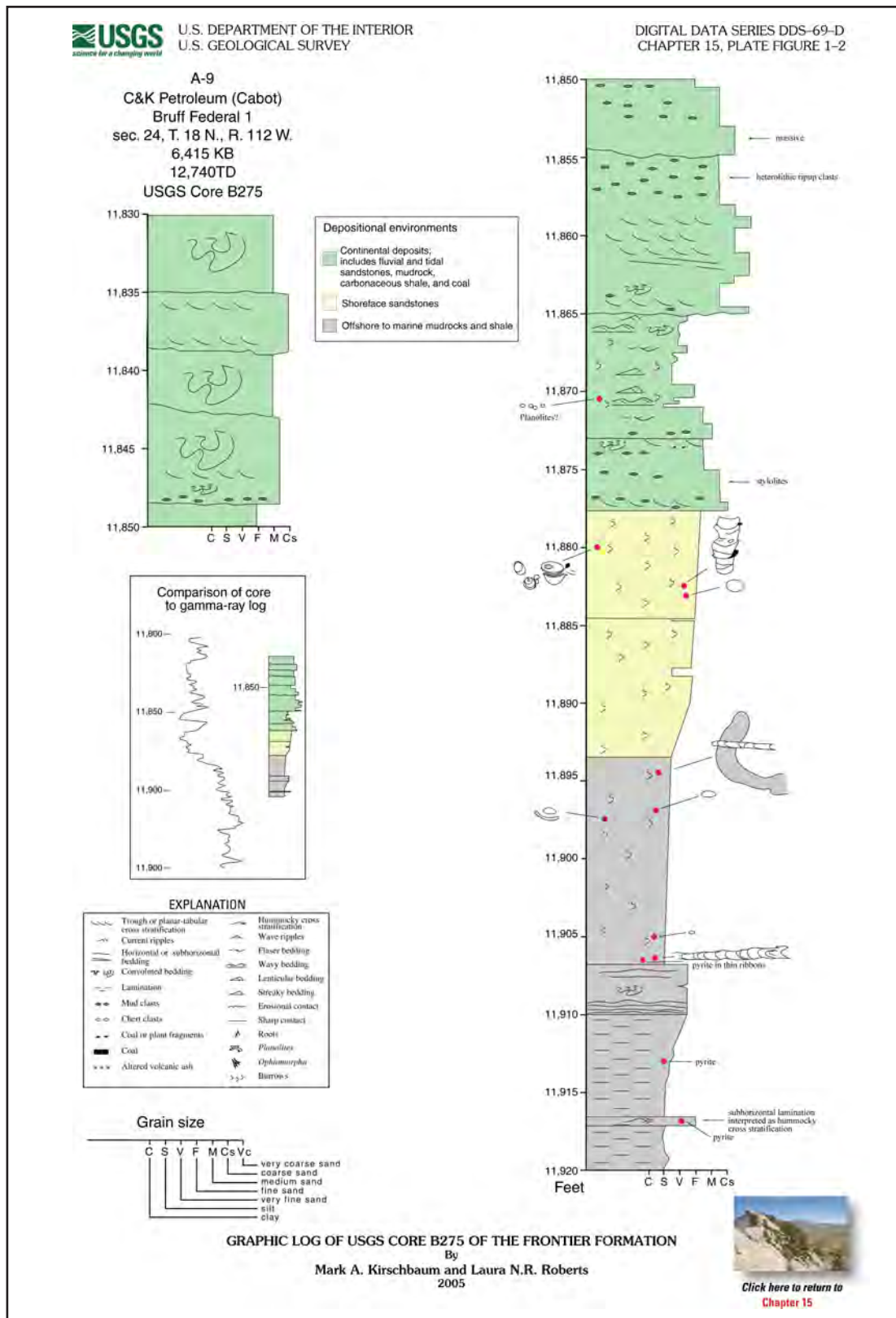


Plate figure 1-2. Graphic log of USGS core B275 of the Frontier Formation. The described core is in the depth interval 11,830–11,920 feet. Trace fossil sketches are true scale. Abbreviations: KB, Kelly bushing; TD, total depth.

Click on image below to bring up high-resolution image of plate 2.

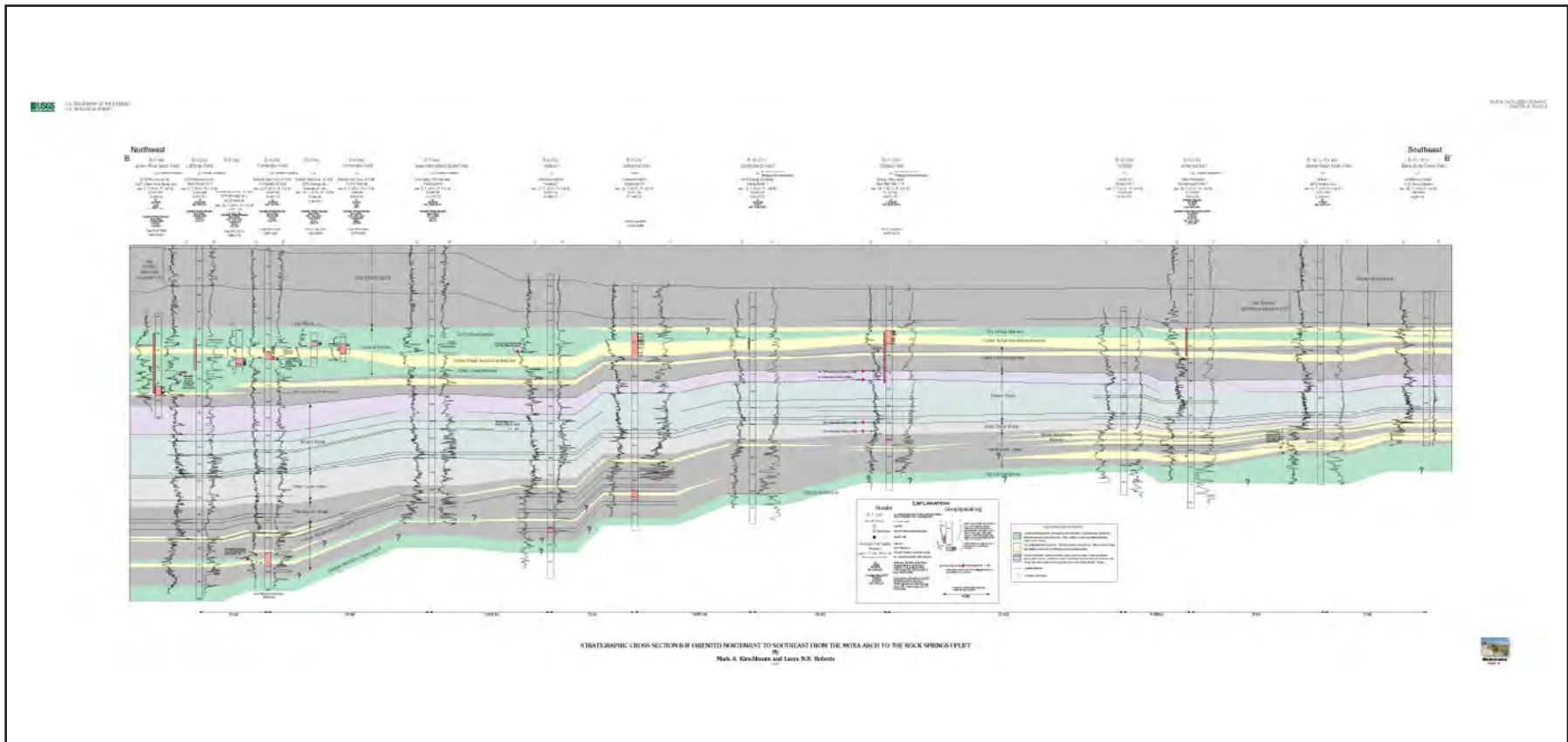


Plate 2. Stratigraphic cross section B-B' oriented northwest to southeast from the Moxa arch to the Rock Springs uplift. Location of section shown in figure 1. Wells were projected into a single line of section.

Click on image below to bring up high-resolution image of plate figure 2-1.

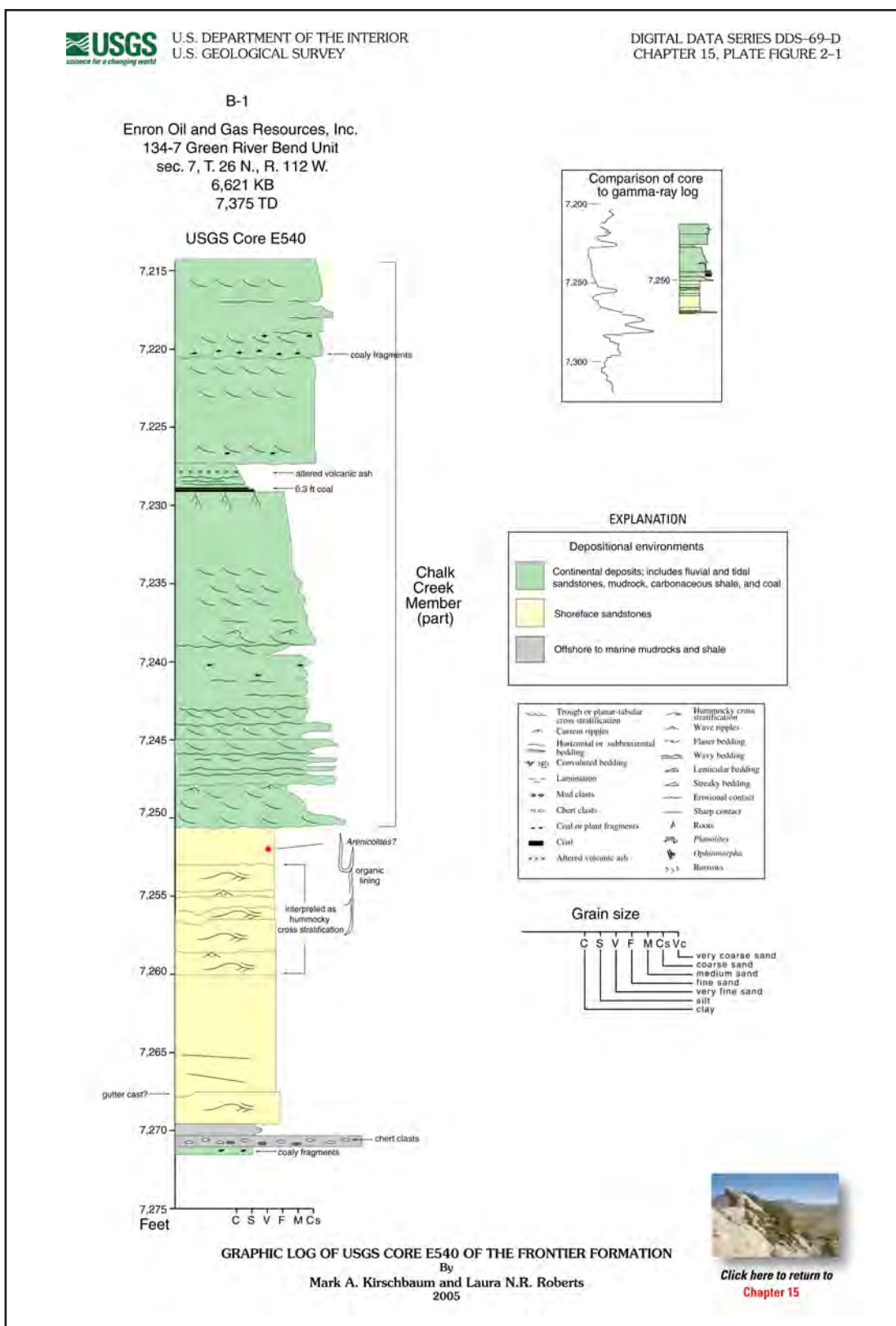


Plate figure 2-1. Graphic log of USGS core E540 of the Frontier Formation. The described core is in the depth interval 7,214–7,271.5 feet. Trace fossil sketches are true scale. Abbreviations: KB, Kelly bushing; TD, total depth.

Click on image below to bring up high-resolution image of plate figure 2-2.

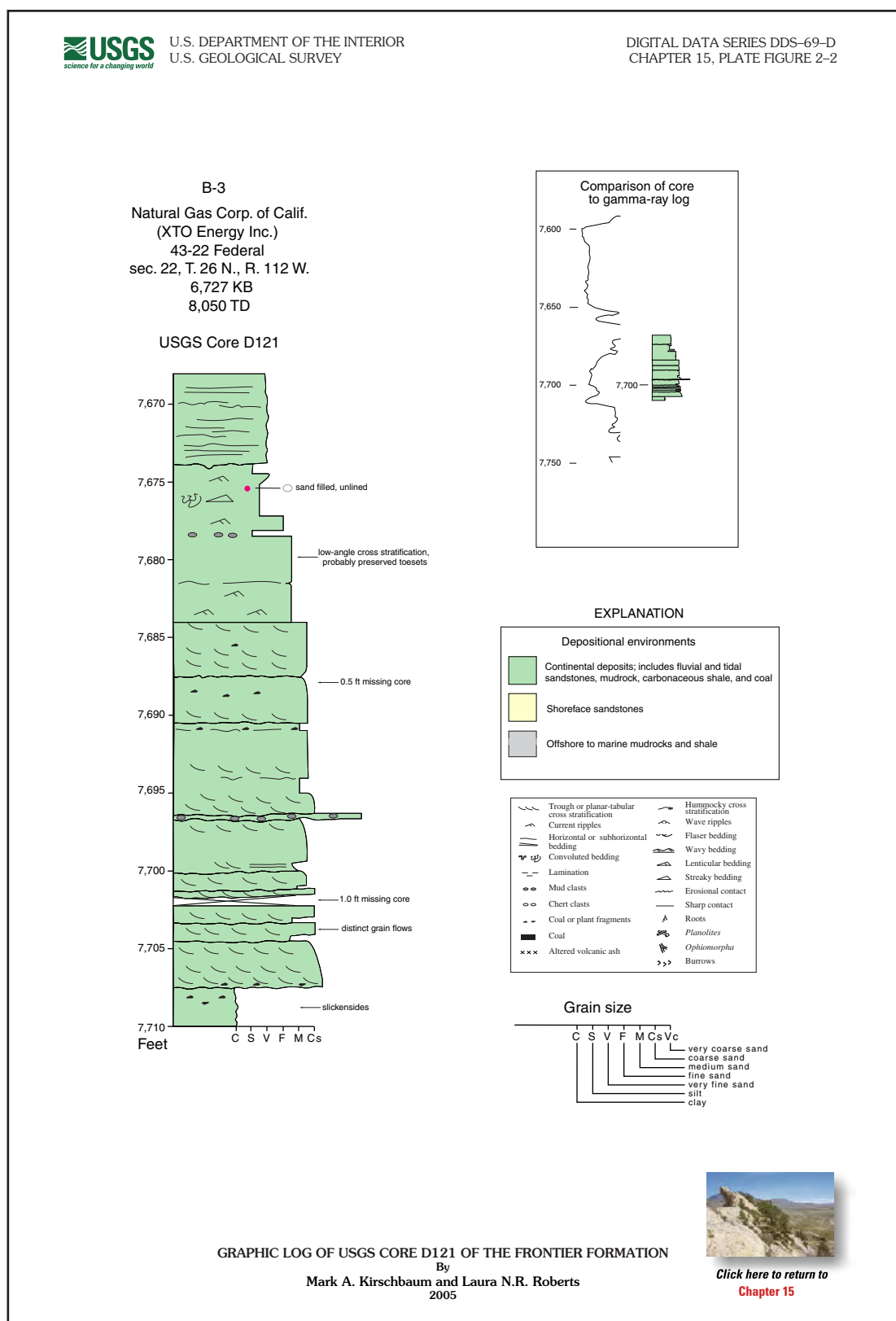


Plate figure 2-2. Graphic log of USGS core D121 of the Frontier Formation. The described core is in the depth interval 7,668–7,710 feet. Abbreviations: KB, Kelly bushing; TD, total depth.

Click on image below to bring up high-resolution image of plate figure 2–3.

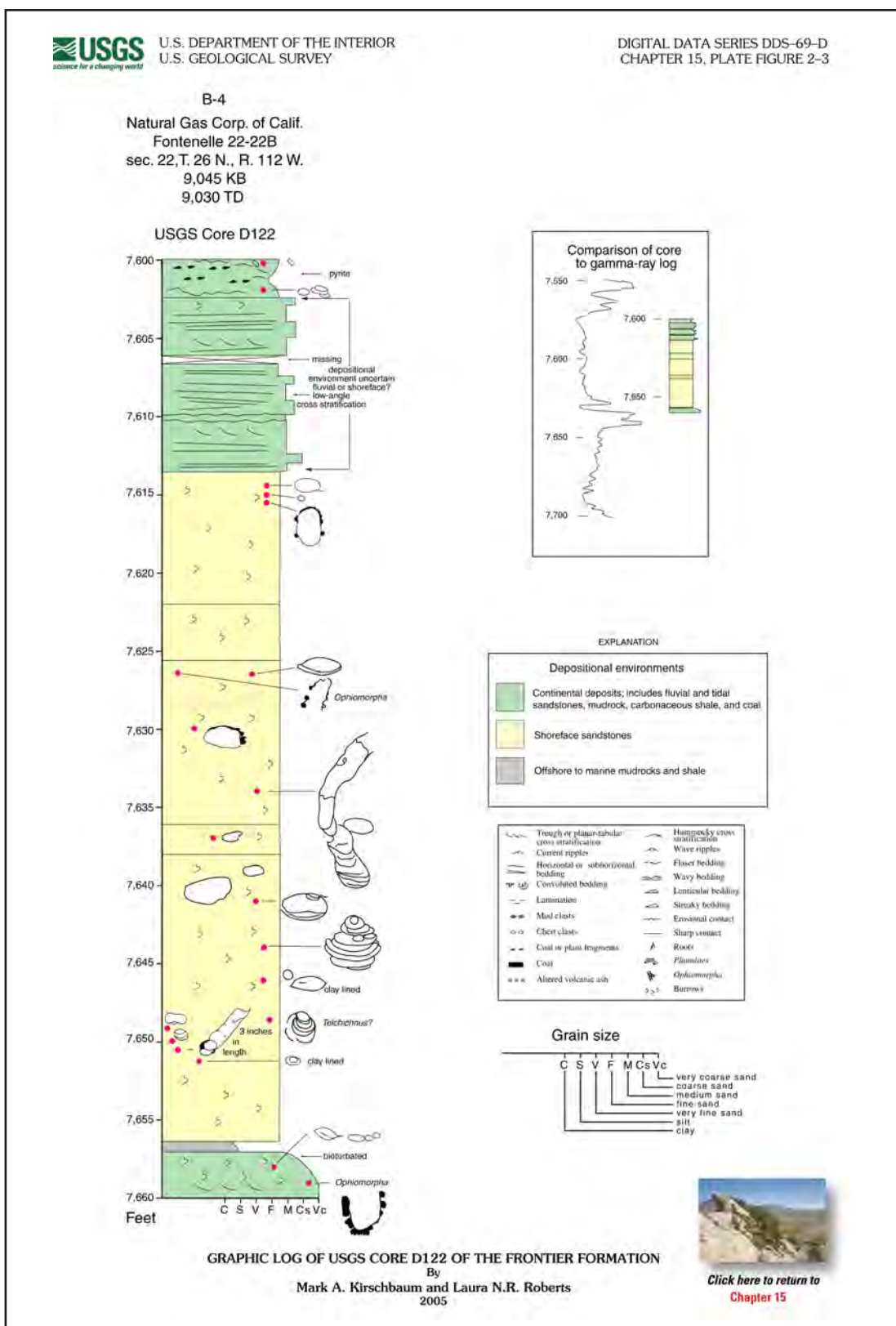


Plate figure 2-3. Graphic log of USGS core D122 of the Frontier Formation. The described core is in the depth interval 7,600–7,660 feet. Trace fossil sketches are true scale. Abbreviations: KB, Kelly bushing; TD, total depth.

Click on image below to bring up high-resolution image of plate figure 2-4.

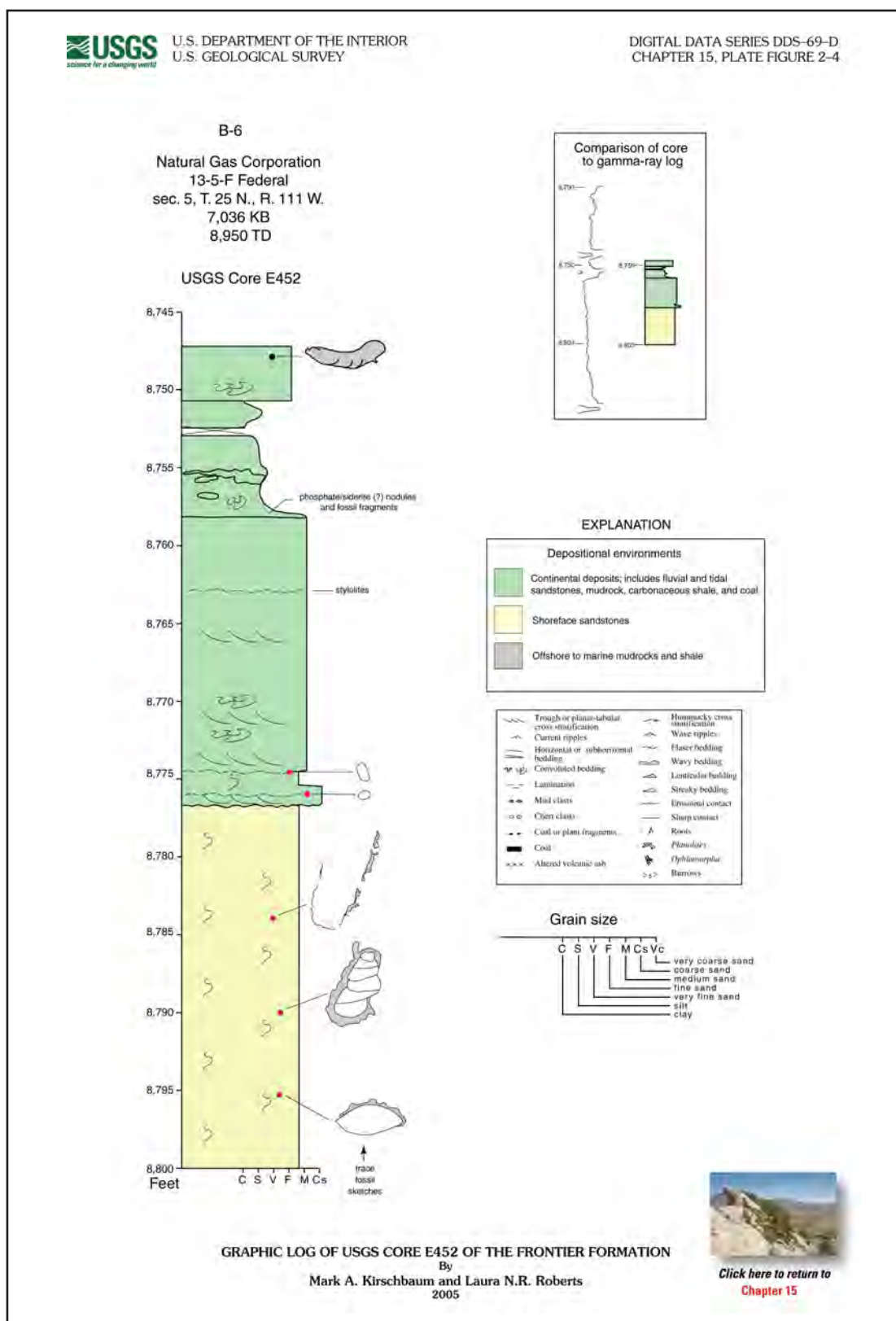


Plate figure 2-4. Graphic log of USGS core E452 of the Frontier Formation. described core is in the depth interval 8,747–8,800 feet. Trace fossil sketches are true scale. Trace fossil sketches are true scale. Abbreviations: KB, Kelly bushing; TD, total depth.

Click on image below to bring up high-resolution image of plate figure 2–5.

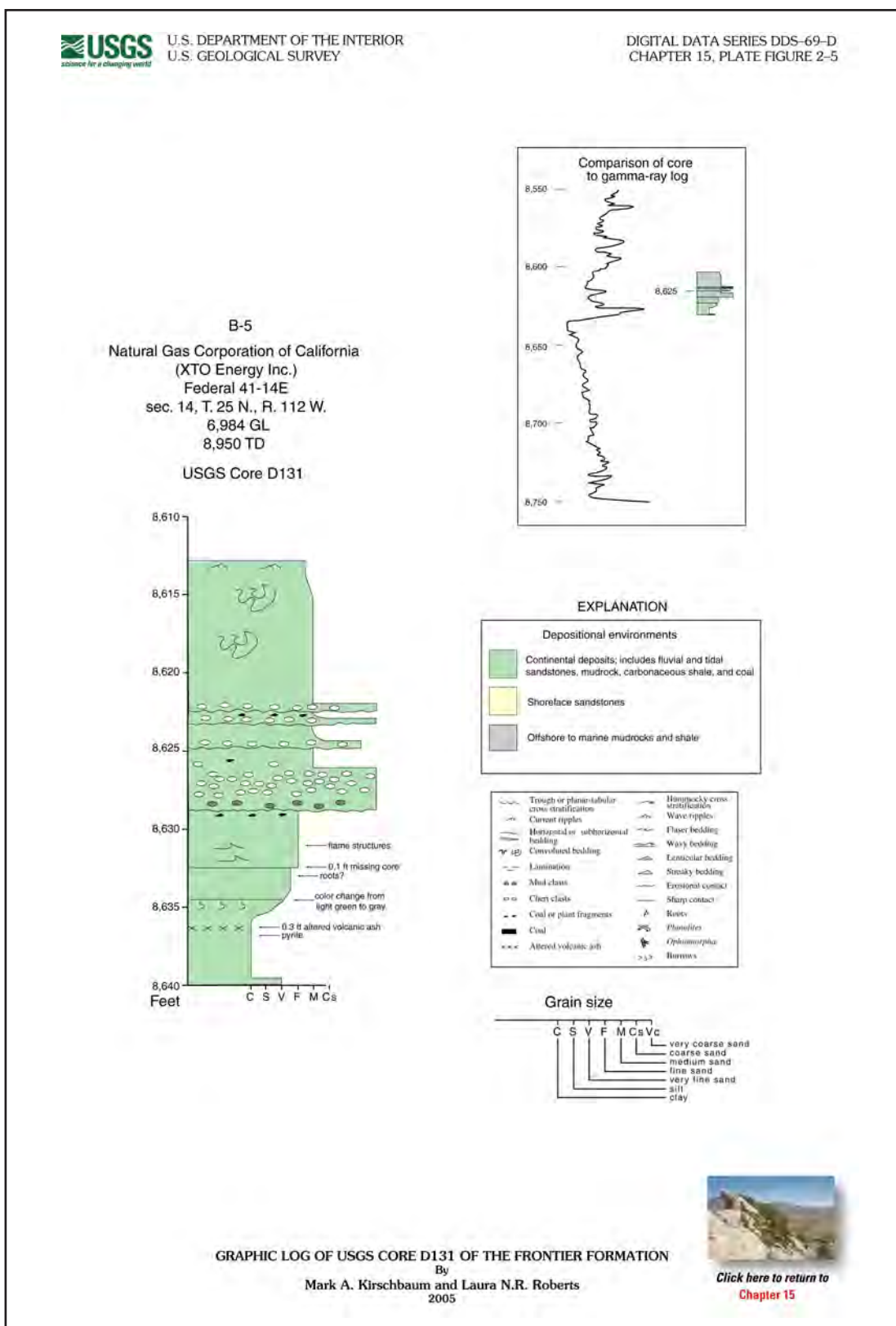


Plate figure 2-5. Graphic log of USGS core D131 of the Frontier Formation. The described core is in the depth interval 8,613–8,640 feet. Abbreviations: KB, Kelly bushing; TD, total depth.

Click on image below to bring up high-resolution image of plate figure 2-6.

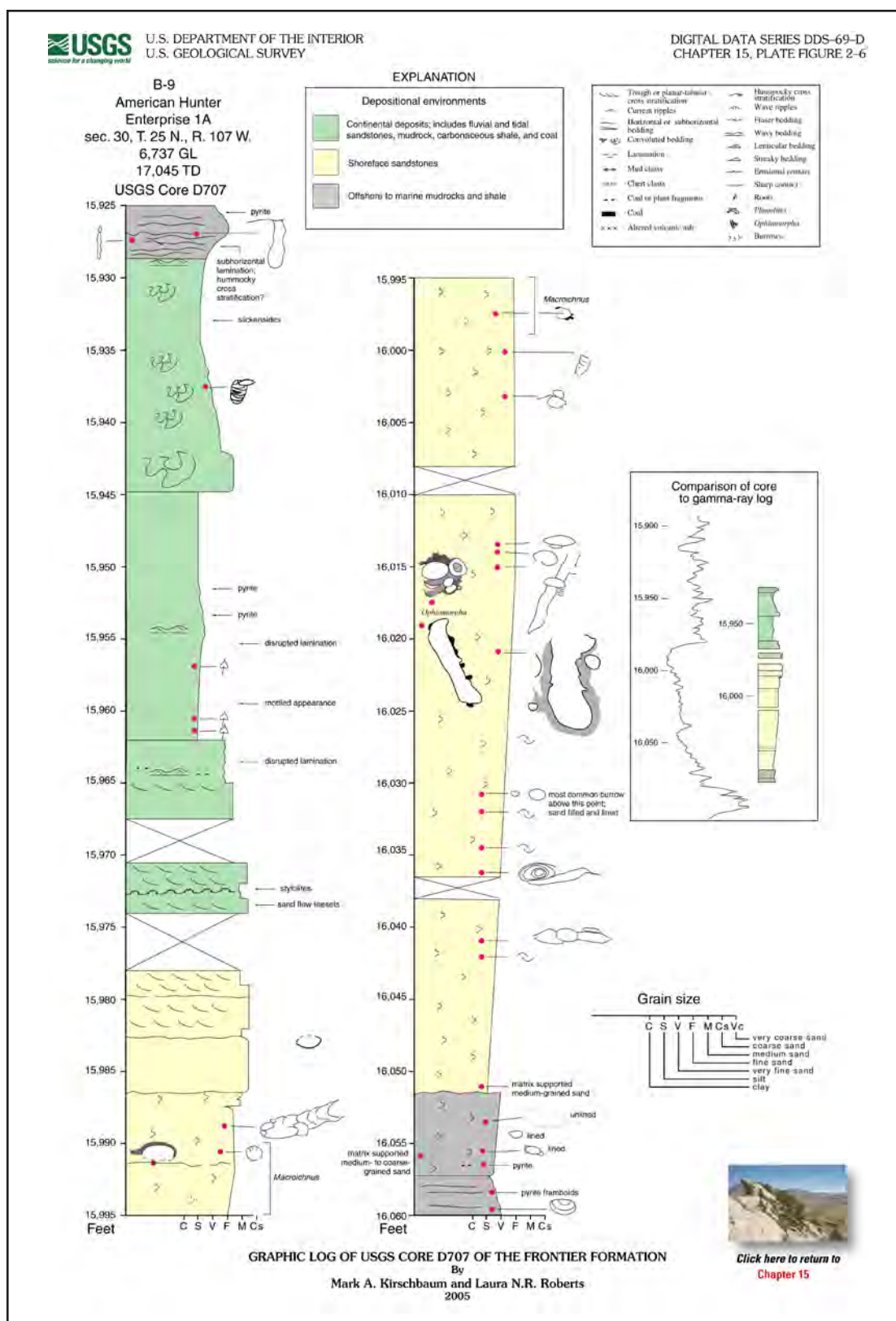


Plate figure 2-6. Graphic log of USGS core D707 of the Frontier Formation. The described core is in the depth interval 15,925–16,060 feet. Trace fossil sketches are true scale. Abbreviations: KB, Kelly bushing; TD, total depth.

Click on image below to bring up high-resolution image of plate figure 2-7.

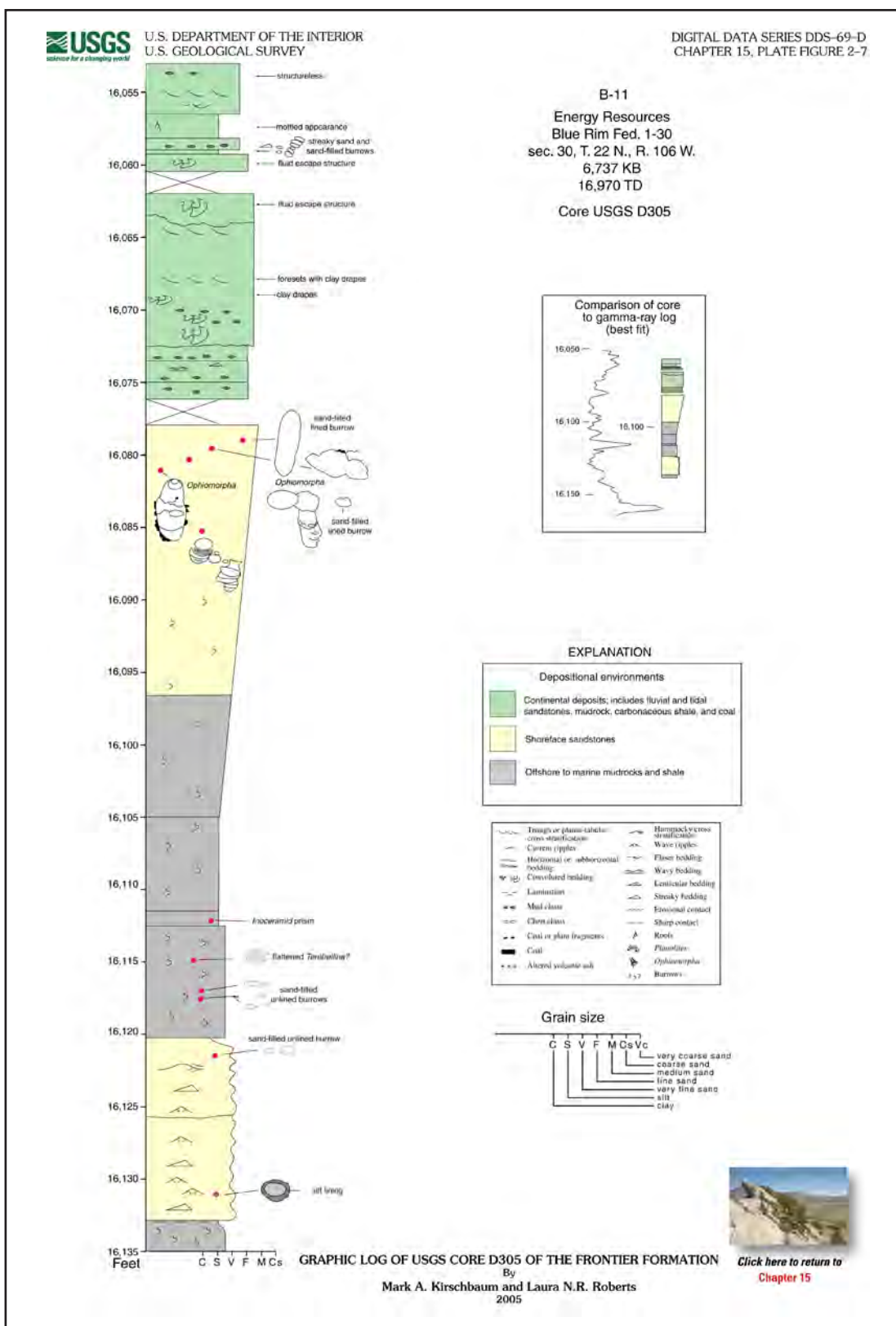


Plate figure 2-7. Graphic log of USGS core D305 of the Frontier Formation. The described core is in the depth interval 16,047–16,135 feet. Trace fossil sketches are true scale. Abbreviations: KB, Kelly bushing; TD, total depth.

Click on image below to bring up high-resolution image of plate 3.

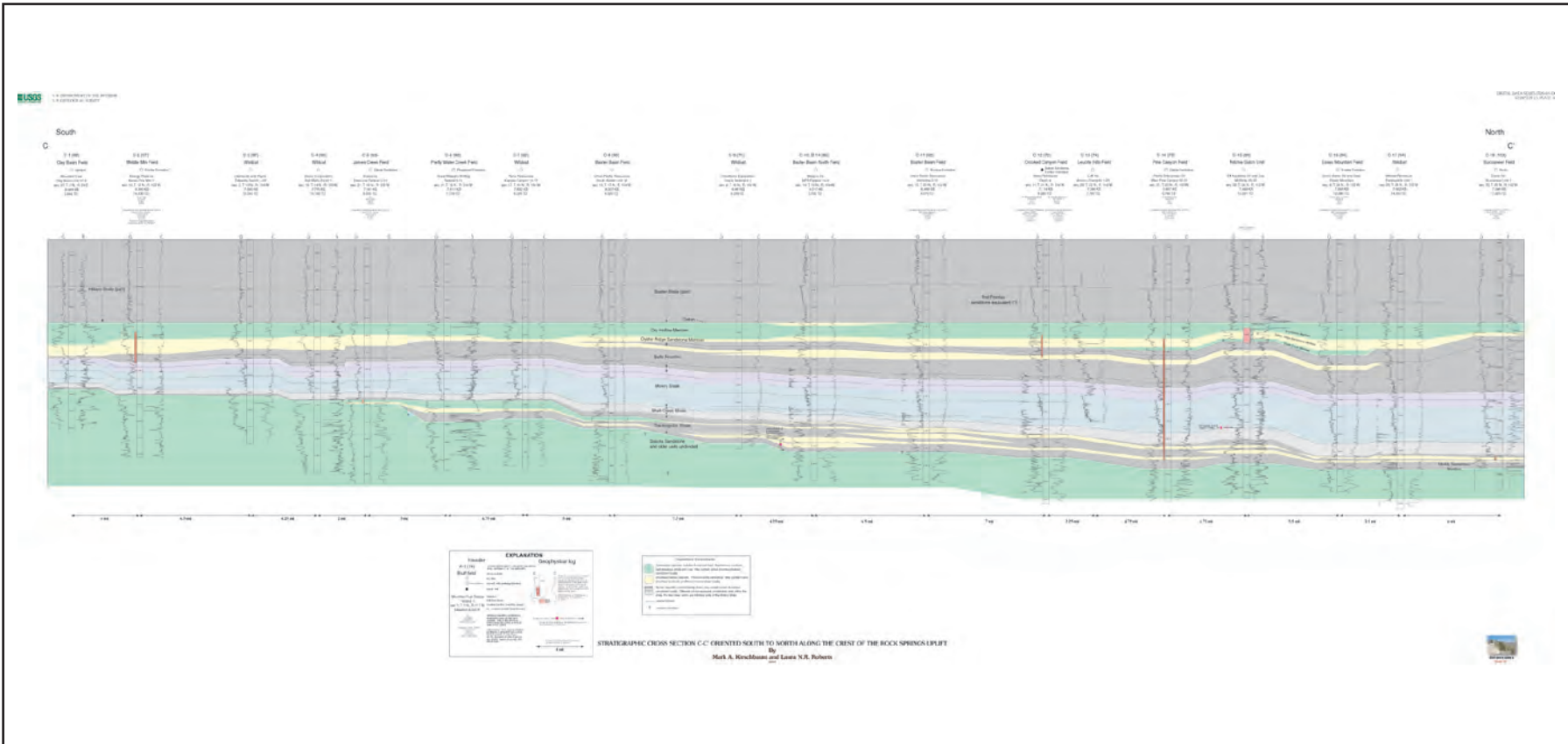


Plate 3. Stratigraphic cross section C-C' oriented south to north along the crest of the Rock Springs uplift. Location of section shown in figure 1. Wells were projected into a single line of section.

Click on image below to bring up high-resolution image of plate figure 3-1.

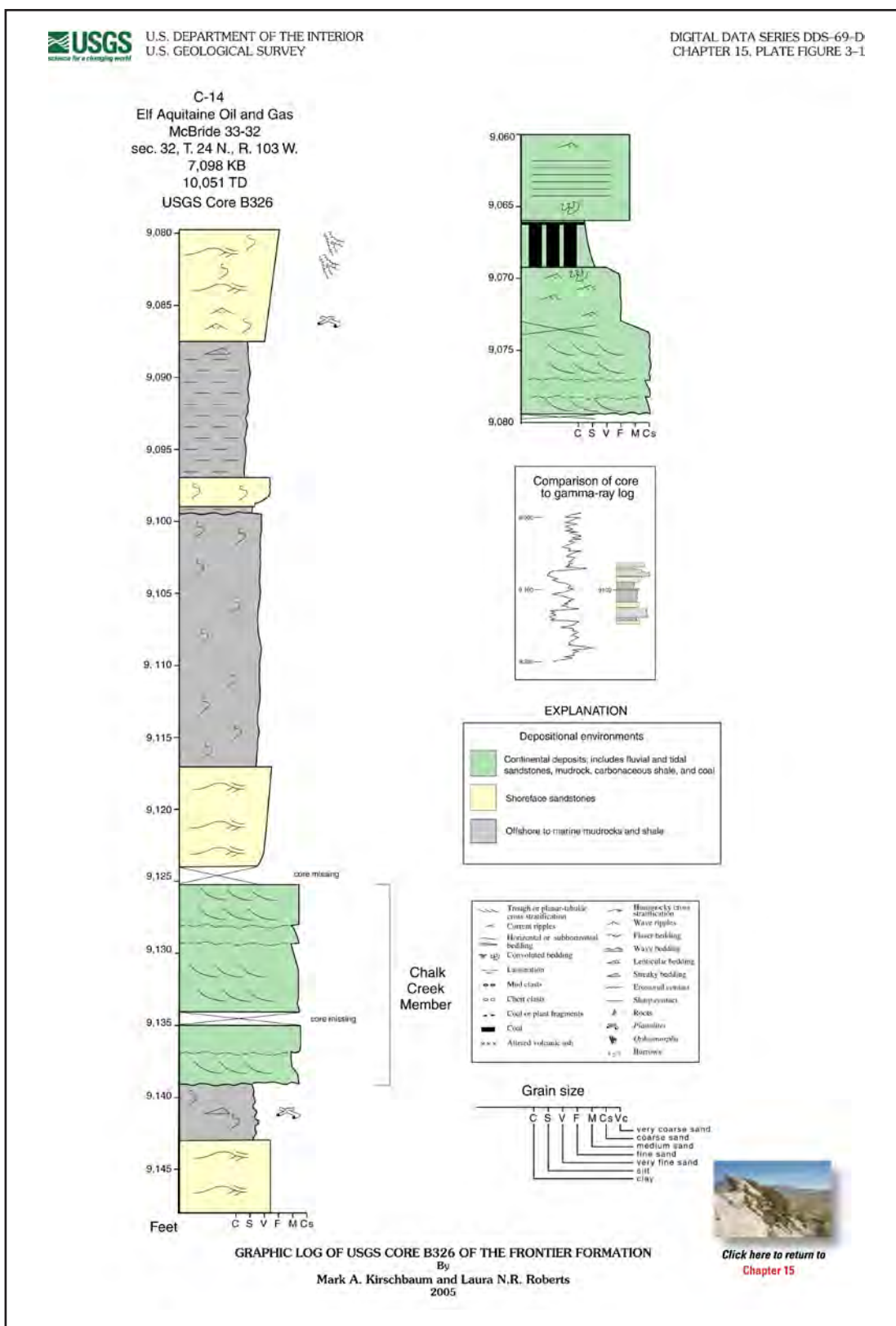


Plate figure 3-1. Graphic log of USGS core B326 of the Frontier Formation. Described core is in the depth interval 9,060–9,148 feet. Abbreviations: KB, Kelly bushing; TD, total depth.

Click on image below to bring up high-resolution image of plate 4.

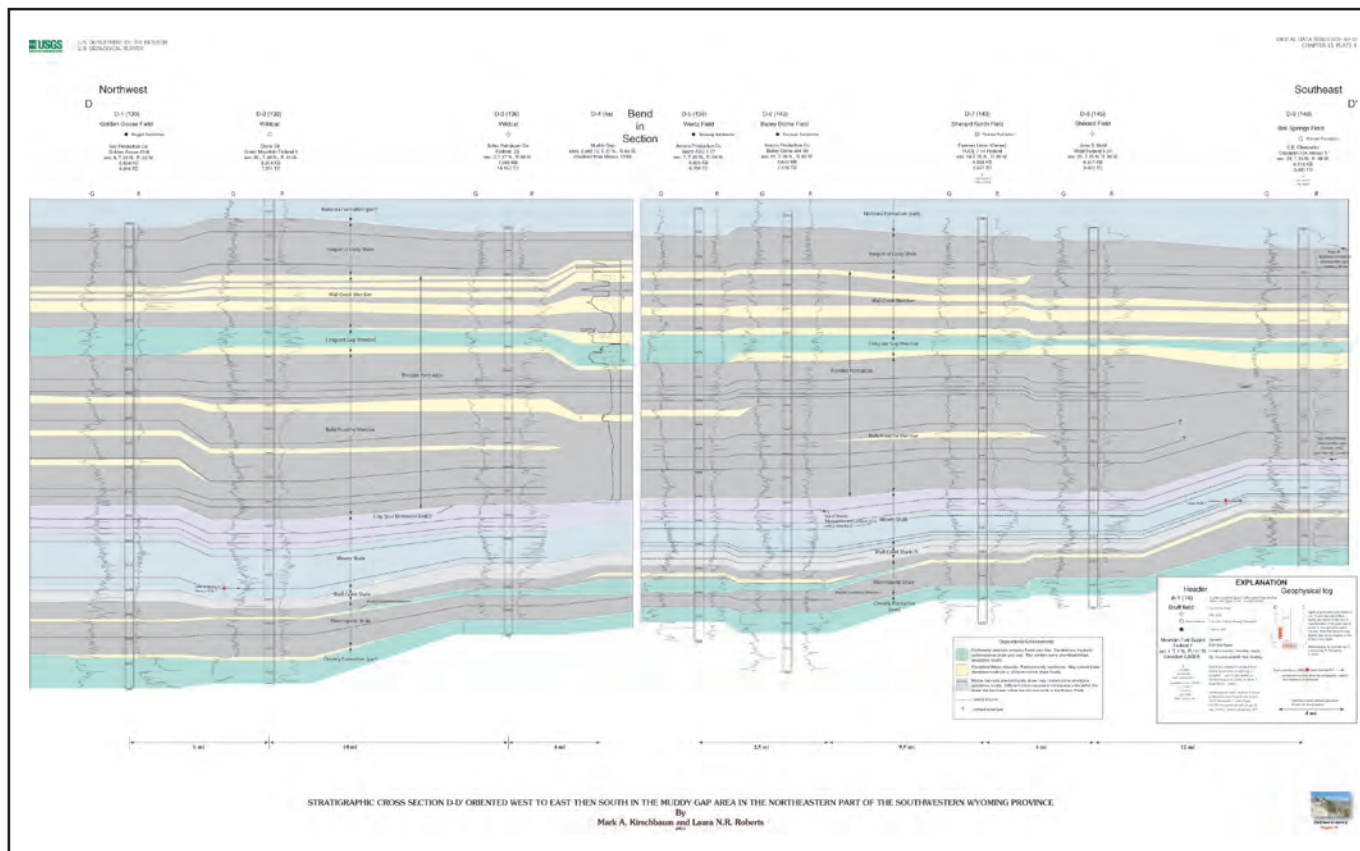


Plate 4. Stratigraphic cross section D–D' oriented northwest to southeast in the Muddy Gap area in the northeastern part of the province. Location of section shown in figure 1. Wells were projected into a single line of section.



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